CONCRETE ENGINEERS' HANDBOOK

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PREFACE

India is making steady progress in all directions and in civil engineering she has some of the largest construction works in the world to her credit. It may, however, be said without any fear of contradiction that her strength of civil engineers is much less than her requirements. Except on government and semi-government projects and in cities like Bombay where qualified consulting engineers are available, a very large percentage of public building activity is today managed by the humble maistry or overseer or a contractor with little or limited theoretical background. Even in the case of qualified engineers we are afraid there may be several who have to construct a concrete structure only occasionally in their career in a drainage, irrigation, or water supply department. It may not be expected of them to remember all the long formulæ of reinforced concrete design together with the methods of their application.

This handbook is written specially for the convenience of such people. A specialist in concrete engineering who invariably has his own tables of reference may not find this book indispensable but we are sure where preliminary investigations and estimates are to be made he will save considerable time by reference to various tables in the handbook.

Large portions of India are alluvial tracts where good broken stone and coarse sand are not available and the use of imported material is very costly. The local material, even though of sub-standard quality, has to be used. Similarly in case of steel, it is necessary to use bars made from scrap steel by local rolling factories. In such places it is advisable to use lower stresses and hence tables, charts, etc. giving concrete sections

according to the old L.C.C. Regulations (1909) which may appear too orthodox to one unfamiliar with mofussil conditions in India have been given purposely. Where conditions are favourable, higher stresses are certainly recommended.

Before concluding this preface it would not be out of place to say a word or two about the most important and much discussed problem of the design of concrete mixes. This aspect of concrete engineering is practically new to the vast majority of Indian engineers who so far were working on the basis of arbitrary mixes found suitable by practice. A method of rationally designing concrete mixes has been given in this handbook and we trust Indian engineers will make extensive use of it henceforth, and let us have the reports of their findings.

Thanks are due to Mr. N. H. Mohile, B.E., M.I.E. (India), M.I. Struct. E. (Lond.) of this Association whose efforts are mostly responsible in bringing out this handbook.

The book is published with a sincere hope that it will fulfil the long felt need for a concise reference book on the design and technology of concrete.

CONCRETE ENGINEERS' HANDBOOK

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CONCRETE ENGINEERS' HANDBOOK

CHAPTER 1

MATERIALS

1.1 PORTLAND CEMENT.

1.1.1 DEFINITION.

Portland Cement is defined as a product obtained by intimately mixing together calcareous and argillaceous and/or other silica, alumina, or iron oxide bearing materials, burning them at a clinkering temperature and grinding the resulting clinker. After burning no material other than gypsum or air entraining agents is added.

1.1.2 VARIOUS KINDS OF CEMENT.

1.1.2.1 Rapid Hardening (also called High Early Strength Cement).

(a) *Materials used for manufacture*: Same as ordinary cement but more carefully prepared and carrying higher lime content.

(b) *Burning Operations*: At a temperature higher than that of ordinary cement.

(c) *Grinding*: Finer than ordinary.

(d) *Setting properties*: Same as ordinary type.

(e) *Hardening properties*: Attains in 3 days the strength of 28 days old normal cement and so saves cost of moulds, etc., by about 30 per cent.

1.1.2.2 }
1.1.2.3 } White Cement and Coloured Cement.

(NOTE.—White cement is not made in India. Snowcrete, Atlas, etc., are generally used.)

(a) *Materials used for manufacture*: Pure limestone free from any iron content.

(b) *Strength, etc.*: Up to B.S.S., but slightly less than normal cement.

Coloured cement is made by mixing white cement with inorganic colours about 5 to 10% at the time of grinding.

1.1.2.4 Aluminous (also called High Alumina) Cement.

[Not made in India. Imported brands are: *Ciment Fondu* Lightning (U.K.), Lumnite (U.S.A.) etc.]

(a) *Manufacture*: Mixture of bauxite and lime is heated to fusion at high temperature.

(b) *Setting*: Sets within one hour.

(c) *Hardening*: Very rapid. 100 days strength of ordinary cement is developed within 24 hours.

(d) *Special qualities*: Immune from attacks of sea-water, sulphate bearing waters, frost, etc. Forms excellent refractory concrete stable up to 1500°C.

Precautions: Contamination with ordinary cement to be avoided.

1.1.2.5 Blast Furnace Cement.

(a) *Manufacture*: Clinker of normal Portland Cement is ground with about 65% of granulated slag. The slag should in no case be more than 65%.

(b) *Properties*: Same as ordinary cement.

NOTE: Slag cement is different from blast furnace cement being a mixture of lime and blast furnace slag ground together.

1.1.2.6 Masonry Cement.

(a) *Manufacture*: Ordinary Portland Cement is mixed with hydrated lime or calcium or aluminium stearate or paraffin oil.

(b) *Properties*: Gives more workable and plastic mortar and hence more suitable for masonry and plaster works.

1.1.2.7 Low Heat Cement.

(a) *Properties*: Less heat is evolved during setting. Hence more suitable for large mass concrete works, where heat of hydration does not dissipate easily and so cracks the concrete after cooling.

1.1.2.8 Air Entraining Cement.

(a) *Manufacture*: Rosin and Vinsol resin or vegetable fats and oils such as tallow and olive oil and other fatty acids such as stearic and oleic acids are ground with ordinary cement.

(b) *Properties*: Development of microscopic air bubbles while setting forms minute voids in the concrete and increases its resistance against freezing and scaling action of salts like Calcium Chloride, etc. Three to five per cent air trapped in the concrete in the form of tiny individual bubbles improves the

workability of the concrete, permitting a reduction in the water cement ratio, reduces shrinkage and improves durability, etc.

1.1.2.9 Pozzolanic or Silica Cement.

(a) *Manufacture*: Ordinary cement clinker and pozzolana (about 30%) are ground together. The pozzolana may be natural such as diatomaceous earth or pumice, or artificial such as burnt clay.

(b) *Properties*: The pozzolana reacts with free lime in the concrete which otherwise is affected by corrosive water. Addition of pozzolana also improves such qualities of the concrete as water-tightness and fire resistance. The concrete is also of low heat type.

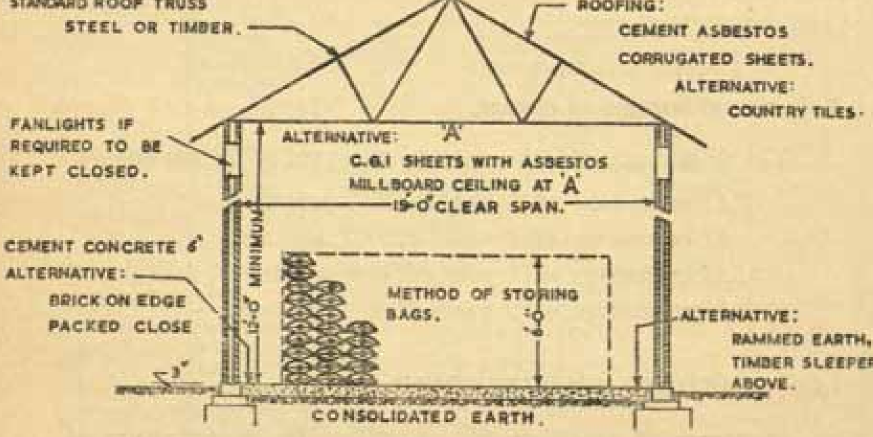
1.1.2.10 Modified Cement.

Gives lower heat of hydration than normal cement and has improved resistance to sulphates.

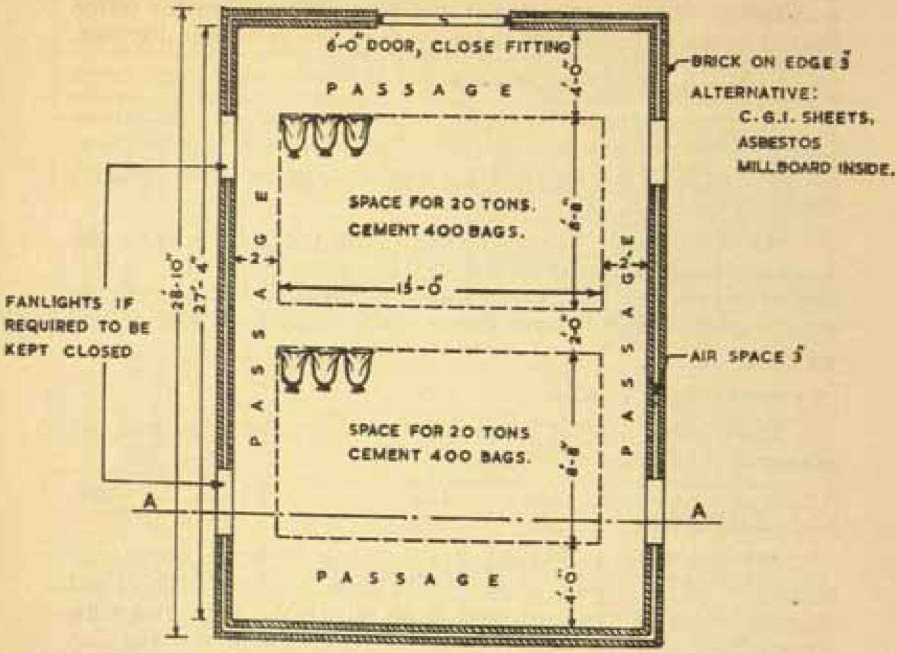
1.1.3 STORAGE.

All possible precautions for keeping moisture away are necessary. The storage shed should have a pucca floor raised at least 6 inches from ground, with air-tight doors and windows. Bulk storage is preferable for longer interval. Fig. 1-1 gives a design of an ideal godown.

SUGGESTED BUILDING FOR STORING
40 TONS PORTLAND CEMENT



SECTION ON A-A



PLAN

Fig. 1-1.

Reduction of Strength in Storage.

The following reduction may be expected at 28 days:—

After storage of 3 months 20% minimum.
After storage of 6 months 30% minimum.
After storage of 1 year 40% minimum.
After storage of 2 years 50% minimum.

1.1.4 STANDARD SPECIFICATIONS.

Summary of specifications controlling the manufacture of various cements, used in India is given on the facing page:—

PROPERTIES OF CEMENT.

TYPE OF CEMENT		ORDINARY PORTLAND CEMENT	RAPID-HARDENING PORTLAND CEMENT (1)	PORTLAND BLASTFURNACE CEMENT	LOW-HEAT PORTLAND CEMENT	HIGH-ALUMINA CEMENT
STANDARD		I. S. 269 (1951)	I. S. 269 (1951)	B. S. № 146 (1947)	B.S. № 1370 (1947)	B.S. № 915 (1947)
FINENESS (4)	MINIMUM RESIDUE BY WEIGHT ON B.S. SIEVE № 170 (2)	10 PER CENT	5 PER CENT	10 PER CENT	—	8 PER CENT
	MINIMUM SPECIFIC SURFACE (6) SQ. CM PER GM	2250 (1600)	3250 (1700)	2250	3200 (1700)	2250
MINIMUM TENSILE STRENGTH (3) LB. PER SQ. IN.	1 DAY	—	300	—	—	—
	3 DAYS	300	450	300	—	—
	7 DAYS	375	—	375	—	—
MINIMUM COMPRESSIVE STRENGTH (3) LB. PER SQ. IN.	1 DAY	—	1000	—	—	6000
	3 DAYS	1600	3500	1600	1000	7000
	7 DAYS	2500	—	2500	1600	—
	28 DAYS	—	—	—	3750	—
SETTING TIMES (HOURS)	INITIAL	NOT LESS THAN ½			$\nless$ 1	$\nless$ 2 $\ngtr$ 6
	FINAL	NOT LESS THAN 10			$\ngtr$ 10	$\ngtr$ 2 AFTER INITIAL SET
SOUNDNESS	EXPANSION (LE CHATELIER)	NOT MORE THAN 10 mm (0.40 IN.)				$\ngtr$ 1 mm (0.40 IN.)
HEAT OF HYDRATION	7 DAYS 28 DAYS	NONE SPECIFIED			CALS. PER GM. $\ngtr$ 65 $\ngtr$ 75	NONE SPECIFIED
CHEMICAL COMPOSITION	$S = SiO_2$ $A = Al_2O_3$ $F = Fe_2O_3$ $C = CaO$	$\frac{C}{2{\cdot}8S + 1{\cdot}2A + 0{\cdot}65F} \nless 0{\cdot}66 \ngtr 1{\cdot}02$ $\frac{A}{F} \nless 0{\cdot}66$		BLAST FURNACE SLAG $\ngtr$ 65 PER CENT (CEMENT CLINKER TO COMPLY WITH B.S. № 12)	$C \ngtr 2{\cdot}4S + 1{\cdot}2A + 0{\cdot}65F$ $\nless 1{\cdot}9S + 1{\cdot}2A + 0{\cdot}65F$ $\frac{A}{F} \nless 0{\cdot}66$	$\frac{A}{C} \nless 0{\cdot}85 \ngtr 1{\cdot}3$ $A \nless$ 32 PER CENT
	ADMIXTURE AFTER BURNING	NONE (EXCEPT GYPSUM OR WATER OR AIR ENTRAINING AGENTS (1% MAXIMUM)			NONE (EXCEPT GYPSUM AND WATER)	NONE (EXCEPT WATER)
	MgO SO_3	$\ngtr$ 5 PER CENT $\ngtr$ 2·75 PER CENT		$\ngtr$ 5 PER CENT $\ngtr$ 5 PER CENT (5)	$\ngtr$ 5 PER CENT $\ngtr$ 2·75 PER CENT	—
	INSOLUBLE RESIDUE LOSS ON IGNITION	$\ngtr$ 1 PER CENT $\ngtr$ 4 PER CENT				—
NOTES	1. "HIGH EARLY STRENGTH CEMENT" 2. NOMINAL SIZE OF APERTURE: 0·0035 IN. 3. ALTERNATIVE TESTS. STRENGTH AT ANY AGE MUST BE GREATER THAN STRENGTHS AT EARLIER AGES 4. ALTERNATIVE TESTS (EXCEPT FOR LOW HEAT PORTLAND CEMENT) 5. AS SO_3: $\ngtr$ 2 PER CENT.; AS SULPHIDE: $\ngtr$ 1·2 PER CENT. 6. BRACKETED FIGURES FOR TURBIDIMETER METHOD					

Fig. 1-2.

1.1.5 ADULTERATION.

Field Test for Adulteration.

(a) A sample of doubtful stuff should be burned for about 20 minutes on a steel plate heated by a stove. Adulterated sample changes its colour, while unadulterated cement remains unchanged.

(b) Make small pats, say $2'' \times 2'' \times \frac{1}{2}''$ with adulterated and genuine cement. Pats made with doubtful cement can be broken easily with pressure of your fingers.

It is always advisable to send the sample to laboratory for full analysis and tests.

1.1.6 USEFUL MEMORANDA ON CEMENT.

1 jute bag contains 110½ lbs. of cement (about 1.2 cft.).

1 ton of Portland Cement=20 jute bags=24 cft.

1 barrel of cement weighs 376 lbs.

6 barrels of cement make 1 ton (Metric).

1 cft. of cement loosely filled weighs 85 to 90 lbs.

1 cft. of cement tightly packed weighs 110 lbs.

Atlas white cement (American) weighs 94 lbs. per cft.

Snowcrete white cement (English) weighs 85 lbs. per cft.

Ferrocrete Rapid Hardening Cement weighs 75 lbs. per cft.

Ciment Fondu Aluminous Cement weighs 87 lbs. per cft.

1 cubic yard of cement=1-1|12 tons.

1 cubic foot of loose cement neat as cement paste will cover about 10.4 sq. ft. (1 inch thick).

1 cft. of neat cement (90 lbs.) will cover 2.2 sq yds. (½" thick).

1 cft. of neat cement (90 lbs.) will cover 1.9 sq. yds. (⅝" thick).

1 cft. of neat cement (90 lbs.) will cover 1.7 sq. yds. (¾" thick).

1 cft. of neat cement (90 lbs.) will cover 1.4 sq. yds. (⅞" thick).

1 cft. of neat cement (90 lbs.) will cover 1.1 sq. yds. (1" thick).

1 cft. of loose Portland Cement will make:

4.3 cft. of 1 : 2 : 4 concrete.
5.0 cft. of 1 : 2½ : 5 concrete.
5.8 cft. of 1 : 3 : 6 concrete.
7.5 cft. of 1 : 4 : 8 concrete.

1.2. AGGREGATES.

1.2.1 DEFINITION.

Inert material such as sand, pebbles, gravel, crushed stone, etc., which is mixed with Portland Cement and water to produce concrete or mortar is called aggregate.

1.2.2 GENERAL REQUIREMENTS.

Necessary characteristics: The aggregates must be clean, dense, hard, durable, structurally sound, capable of developing good bond with cement, weather-resisting and unaffected by water. Aggregates for road work must have good wearing qualities. When fire-proof construction is needed the aggregates must possess fire-resisting qualities. In case of industrial by-products, blast furnace slag which is a non-metallic product consisting essentially of silicates and alumino silicates of lime and of other base obtained along with iron in a blast furnace, must not contain more than 40% lime. Cinders must be obtained as a product of high temperature combustion and must not contain more than ½% of sulphur and 1% of sulphates. Similarly coke breeze must be free from sulphur and unburnt coal.

1.2.3 SITE TREATMENT OF AGGREGATES.

Site Treatment.—This is necessary if the aggregate as supplied is short of requirement as regards cleanliness and grading. Screening can be done by hand or mechanically to adjust the grading. If the material requires cleansing, washing may be resorted to, but precautions against loss of fine material should be taken. A simple arrangement for mechanical washing device is shown diagramatically in Fig. 1-3.

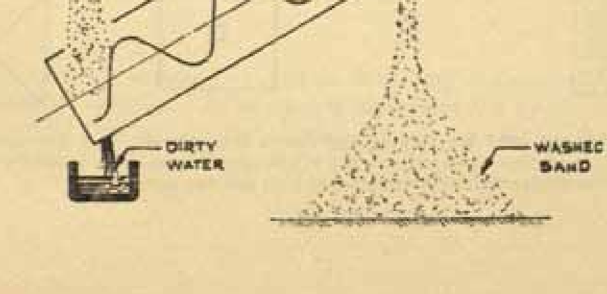


Fig. 1-3.

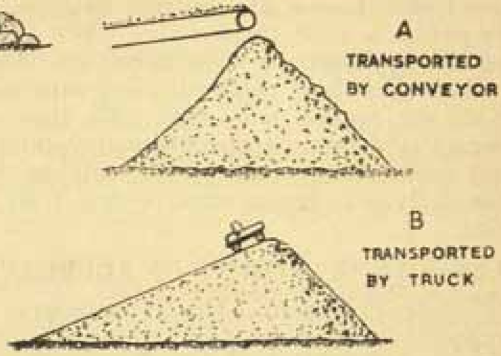
1.2.4 STORAGE OF AGGREGATES.

Precautions.—Avoid storing on dusty, muddy or grassy spots. Dumps must be protected from exposure to dust. Old steel sheets or wooden planks may be used as platforms for storage. On large works storage bins may be used. When stored on ground, the bottom layer of aggregates, say 3″ deep, should be rejected. Correct and incorrect methods of handling and storing aggregates are shown diagrammatically in Fig. 1-4.

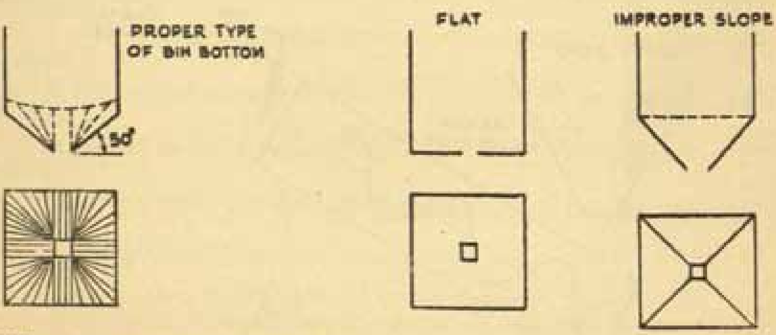
CORRECT

Place aggregates in stock piles in individual units not larger than a truck load and in suitable layers to prevent segregation. [They should not be allowed to run down slopes as shown in B at right].

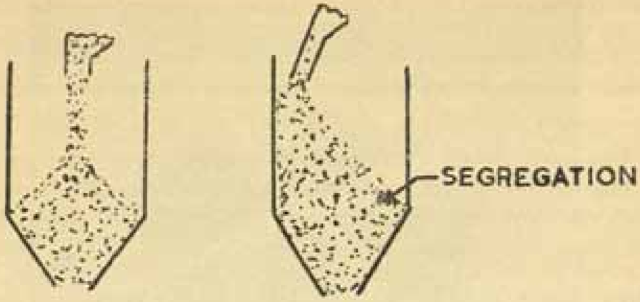
INCORRECT



A. Belt Conveyor, B. truck unloading material at the top of pile and allowing same to run down slope.



When bins are used for storing aggregates they should have bottoms sloping about 50° in all directions and corners of the bottom should be properly rounded. [Flat or insufficiently sloping bottomed bins are not suitable].



While filling the bins material should be made to drop in the centre and not against sides to avoid segregation.

Fig. 1-4.

The aggregates should not segregate into various sizes while storing, otherwise there will be serious difference in the quality of concrete produced.

1.2.5 TESTS ON AGGREGATES.

1.2.5.1 Laboratory Tests.

(a) Sieve Analysis.

(b) Determination of clay, silt and dust.

(c) Determination of organic impurities.

(d) Specific gravity and absorption.

(e) Aggregate crushing test.

(f) Bulk density or unit weight.

(g) Determination of voids.

(h) Test for coal and lignite.

Selection of sample.—Care is necessary to have a fairly representative sample. A large quantity, say 12 cwts., should be collected by taking one cwt. from different heaps. This should be reduced to required quantity by method of quartering as shown in Fig. 1-5.

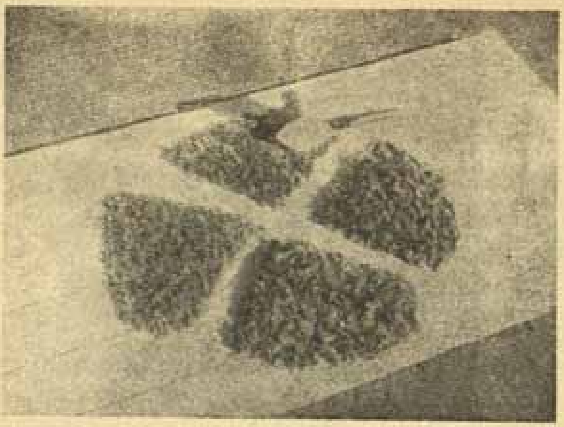


Fig. 1–5. Method of quartering aggregates for sampling.

Minimum quantity.—Different tests require different minimum quantity of aggregates as given below:—

Test	To be supplied to the laboratory	To be tested
Sieve analysis		
$2\frac{1}{2}''$ to $1\frac{1}{2}''$ aggregates	$1\frac{1}{2}$ cwt.	50 lbs.
$\frac{3}{4}''$ to $\frac{3}{8}''$,,	1 cwt.	20 lbs.
Fine ,,	28 lbs.	1 lb.
Determination of Clay etc.		
$2\frac{1}{2}''$ to $1\frac{1}{2}''$ aggregates	1 cwt.	14 lbs.
$\frac{3}{4}''$ to $\frac{1}{4}''$,,	28 lbs.	1 lb.
Fine ,,	2 lbs.	1 lb.
Specific gravity and absorption		
C. aggregates	4 lbs.	2 lbs.
Fine ,,	,,	,,
Aggregate Crushing Strength		
$2''$ to $\frac{3}{4}''$ size	2 cwts.	1 cwt.
$\frac{3}{4}''$ to $\frac{1}{4}''$ size	,,	14 lbs.
Fine aggregates	,,	2 lbs.
Bulk density		
C. aggregate	2 cwts.	75 lbs.
fine aggregate	$\frac{1}{2}$ cwt.	15 lbs.
Voids Test		
C. aggregate		500 ccs.
fine aggregates		100 ccs.

(a) *Sieve Test.*—A known weight of dry aggregates is passed through a set of standard sieves of size 3″, 2½″, 1½″ ¾″, ½″, ⅜″, 3|16″; in case of coarse aggregate, and Nos. 7, 14, 25, 52, 100 in case of fine aggregates, and percentage retained is noted.

(b) *Determination of clay, etc.*—A certain fixed quantity of material is sieved through No. 7 sieve. Material retained on the sieve is washed with sodium oxalate solution of 0.8 grs. per litre strength. This solution is again sieved through No. 7 sieve, and 150 m.l. of this solution taken. This solution is mixed with the material that has passed the No. 7 sieve. A soft rubber pestle is used for mixing the material without causing any attrition. The mixture is kept in a sedimentation tube and after 100 seconds a certain amount is taken in a pipette. This quantity is evaporated in a crucible and weight of residue taken. From this data the percentage of clay, etc., is known.

(c) *Organic Impurities.*—A 12 oz. medicine bottle is filled to 4½ oz. mark with sand and 3% solution of sodium hydro-oxide is added up to 7 oz. mark. The colour of the liquid is compared with standard colour chart.

(d) *Specific Gravity.*—A certain sample of material properly washed to remove dust is dried in an oven and weighed. The sample is then immersed in distilled water and entrained air from the sample is removed by gentle rodding. The sample is then placed in a wire basket suspended in water and weighed. The weight of saturated sample immersed in water is thus obtained. The specific gravity is calculated from the result.

(e) *Aggregate crushing strength.*—A weighed quantity of aggregates is placed in a metal cylinder fitted with a plunger. This plunger is subjected to a specified compression and the aggregate is sieved to remove the material crushed by the compression. The weight of the fines formed is expressed as a percentage of the total sample.

(f) *Bulk density.*—Material held by a container of unit volume when filled under specified conditions is found out.

(g) *Voids.*—A cylindrical metal measure is filled one-third with water and dry aggregate is then added and tamped to exclude air. The process is repeated till the measure is filled to the top and further water added till the measure overflows. The volume of water added gives the volume of voids in the aggregate, from which the required percentage can be calculated.

(h) *Coal and Lignite.*—This is found by removing the particles by floatation in a liquid with a specific gravity of 2 (made from a mixture of carbon tetrachloride and acetylene tetrabromide).

1.2.5.2 Field Tests.

Sieve analysis is done in the same way as above but all the sieves are not necessary.

Silt Test.—A glass vessel is filled half with sand, and water is added up to three-fourth height. After shaking vigorously the contents are allowed to settle after one hour. This gives a fair idea about the quantity of silt in the sample.

Organic matter and void tests.—Same as laboratory tests.

1.2.5.3 Particle Shape and Surface Texture.

In addition to above, a report on aggregates should also contain information about particle shape and surface texture of the aggregates as per following description:—

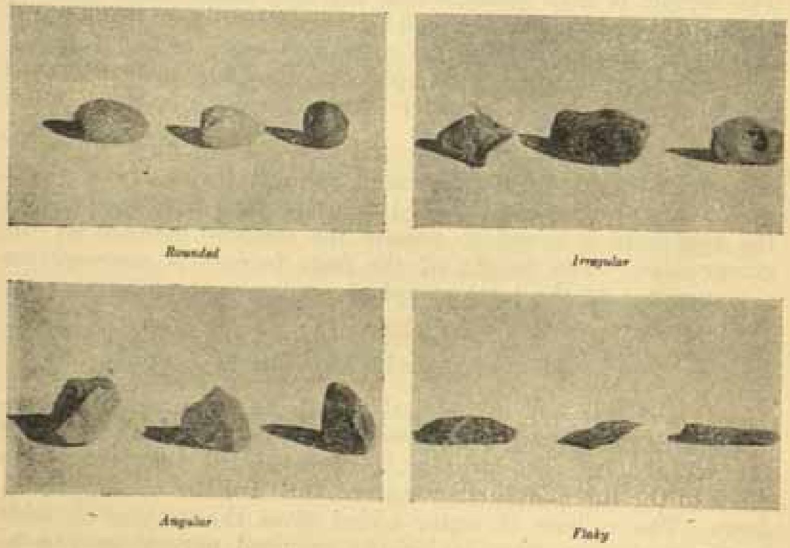


Fig. 1-6. Characteristic specimens of concrete aggregates.

(a) *Particle Shape.*

Classification	Description	Examples.
Rounded	Fully waterworn or completely shaped by attrition.	River gravel, wind blown sand, desert sand etc.
Irregular	Naturally irregular or partly shaped by attrition and having rounded edges.	Pit sand & gravels land or dug flints, cuboid rock etc.
Angular	Having well defined edges.	Crushed rock of all types.
Flaky	Material (usually angular) of which thickness is small relative to width and length.	Crushed rock of all types. Laminated rocks.

(b) *Surface Texture.*

Texture.	Example.
Glassy	Flint, vitrious sand.
Smooth	Slate, Marble etc.
Granular	Sandstone, oolite etc.
Crystalline	Fine Basalt Medium dolerite
Pitted Fine slag	Coarse granite, gneiss etc.
Honey Combed porous	Coarse slag, brick, pumice, etc.

1.2.6 MISCELLANEOUS NOTES.

Bulking of sand.—The volumetric expansion of sand due to moisture content is called Bulking. Finer sands bulk more

than coarser varieties. As the moisture increases and the sand becomes fully saturated, it occupies the same volume as dry sand.

Type of Sand	% Moisture by weight	% Bulking by volume.
Fine	5	38
	10	32
	15	22
	20	10
	27	0
Medium	5	29
	10	22
	15	12
	20	0
Coarse	5	18
	10	12
	15	2

1.2.7 USEFUL DATA ON AGGREGATES.

Weight lbs.|cft.

Fine and dry river sand (loose)	90
Medium "	95
Coarse "	100
Burnt clay ballast	70
Beach or river shingle ¾″ to ¼″	100
Gravel—coarse loose, unscreened	115
Broken brick 2″ to ¾″ gauge	80
" stone "	100
Stone screening ¾″ to ½″	90
Broken granite 2″ to ¾″	105
Granite chipping ¼″ down	95
Coke Breeze 1″ down	45
Clinker hard furnace 1″ to ¼″	70
Pumice stone	40
Blast furnace slag 1½″ to ¾″	90
Honey comb slag	40

Voids: (Approximate percentages).

Sand (moist and fine)	43
Sand (coarse)	35
Sand (mixed)	38
Sand (dry mixed)	30
Stone screenings	58
Broken stone 1″ and under	46
,, 2″ ,, ...	45
,, 2½″ ,, ...	41

Specific Gravity.

Trap	2.9
Granite	2.7
Slate	2.7
Gravel	2.66
Sand	2.65
Limestone	2.60
Sand stone	2.40

1.3. WATER.

1.3.1 FUNCTION OF WATER.

1.3.1.1 Chemical.

Water and various compounds in cement react chemically in the process of setting and hardening of cement. Portland Cement contains about 65% of lime. For complete hydration of all the lime in 100 lbs. of cement about 21 lbs. of water are required. In setting complete hydration does not take place; hence about 14 lbs. of water are sufficient.

1.3.1.2 Physical.

(a) Water distributes the cement evenly so that every particle of stone and sand is coated by it and brought into intimate contact with each other.

(b) Water acts as lubricant and gives workability to the mixture.

1.3.2 FIELD TESTS FOR WATER.

1.3.2.1 Acids.

Can be detected by litmus paper.

1.3.2.2. Sulphates.

Acidify the water with dilute sulphuric acid and then add a little barium chloride solution. Formation of white precipitate indicates presence of sulphates. This should be compared with the local tap water similarly treated.

1.3.2.3 Chlorides.

Acidify water with a little nitric acid and add a few drops of 10% silver nitrate solution. A thick white precipitate indicates chlorides.

1.3.2.4 Carbondioxide.

Add a few drops of dilute hydrochloric acid. A rapid evolution of CO_2 will then take place.

1.3.3 QUANTITY OF WATER.

(*a*) *Mixing Concrete.*—For exact quantity, detailed information is given in chapter on proportioning of concrete, but for estimating purposes the following figures may be used.

Mix	1 : 3 : 6	1 : 2 : 4	1:1⅔:3⅓	1 : 1½: 3	1 : 1 : 2
Dry aggregates	7½	6½	6	5½	5
Damp aggregates	6½	6	5½	5	4½

(The above figures give quantity of water in gallons per cwt. of cement.)

(b) *Other purposes.*—For washing aggregates, curing, etc., 75 to 80 gallons may be assumed per 100 cft. of concrete work.

1.3.4 USEFUL DATA.

One cft. of water = 6.23 Imperial Gallons.
= 7.48 U.S.A. Gallons.
= 62.4 lbs. (at 60° F.).
One Imperial Gallon = 4.55 litres.
= 4 qrts.
= 0.16 cft.
= 1.2 U.S.A. Gallon.
One U.S.A. Gallon = 0.83 Imperial Gallon.
One ton of water = 1 cubic metre.
= 244 Imperial Gallons.
= 35.9 cubic feet.
One cft. of sea water = 64.1 lbs.

1.4. REINFORCEMENT.

1.4.1 STEEL REINFORCEMENT.

Steel Reinforcement comprises of:

(a) mild steel rods,
(b) cold drawn mild steel wire,
(c) twisted bars, single or double,
(d) welded fabrics,
(e) expanded steel,
(f) ribbed mesh steel sheets acting as shuttering also, and
(g) R.S. sections such as joists, channels, rails, etc.

1.4.2 GENERAL REQUIREMENTS.

(a) Freedom from surface defects.
(b) Freedom from rust scales, (moderate surface rusting may be permitted).
(c) Freedom from oil, grease or paint; (lime or cement wash is permissible).

1.4.3 STRUCTURAL REQUIREMENTS AND OTHER PARTICULARS.

(a) M.S. rods
(b) Cold drawn M.S. Wire }

Material	Size D=Diameter In Inches	Minimum Stress Tons/□″		Elongation		Diameter of Bend
		Yield	Ultimate	Length	%Age	
Mild Steel	Over 1″ ⅜″ To 1″ Below ⅜″	Not specified.	28	4D 8D 8D	24 20 16	3D 2D 2D
Medium Tensile Steel	1½″ To 2″ 1″ To 1½″ ⅜″ To 1″ Below ⅜″	17½ 18½ 19½ Do	33	4D 4D 8D 8D	22 22 18 14	3D 3D 2D 2D
High Tensile Steel	1½″ To 2″ 1″ To 1½″ ⅜″ To 1″ Below ⅜″	21 22 23 Do	37	4D 4D 8D 8D	22 22 18 14	3D 3D 2D 2D
Cold Drawn Wire	All Sizes	Not Specified	37	8D	7½	2D

(c) *Twisted Bars.*

Material	Size D=Diameter In Inches	Minimum Stress Lbs/□"		Elongation.		Diameter of Bend
		Yield	Ultimate	Length	%Age	
Twin Twisted Bars	Over 1"	54,000	63,000	5.7D	16	3D
	7/8" To 1"			5.7D	16	2D
	3/8" To 7/8"			11.3D	14	2D
	Below 3/8"			11.3D	12	2D
Twisted Square Bars	Over 1"	60,000	70,000	4.5D	16	4.2D
	11/16" To 1"	Do	Do	4.5D	16	2.8D
	3/8" To 11/16"	Do	Do	9D	14	2.8D
	Below 3/8"	70,000	80,000	9D	12	2.8D

D = Diameter of one round bar or side of square rod before being twisted.

Isteg Twisted Bars are mild steel bars treated by patent cold twisting and stretching process. The length after twisting is the same as original bars. Faulty rods break in the process of twisting, hence the rods which remain can stand higher stresses being without any defect. Yield point of these rods is at 54,000 lbs. per square inch. Bond stress of 540 lbs. per sq. inch and tensile stress of 27,000 lbs. per sq. inch can be permitted. Hooks, etc., which are required for anchorage can also be omitted and hence there is a saving of 33 per cent in weight of reinforcement.

(d) *Welded Fabrics (Plain and Twisted Steel).*—Several fabrics are available, names of a few being:

1. B.R.C.
2. Maxweld
3. Matobar
4. Twist Steel
5. Spun Groove, etc.

Manufacture of plain fabrics is controlled by B.S.S. 1221.

The fabric is to consist of main wires and cross-wire electrically welded.

The fabric is to be made of hard drawn steel wire complying with B.S.S. 785 and can be made both in oblong and square mesh. All joints and junctions are to be electrically welded.

For twisted steel fabrics, cold twisted steel bars complying with B.S.S. 1144 are to be used. In case of oblong mesh, crossbars may be of plain hard-drawn steel wire complying with B.S.S. 785.

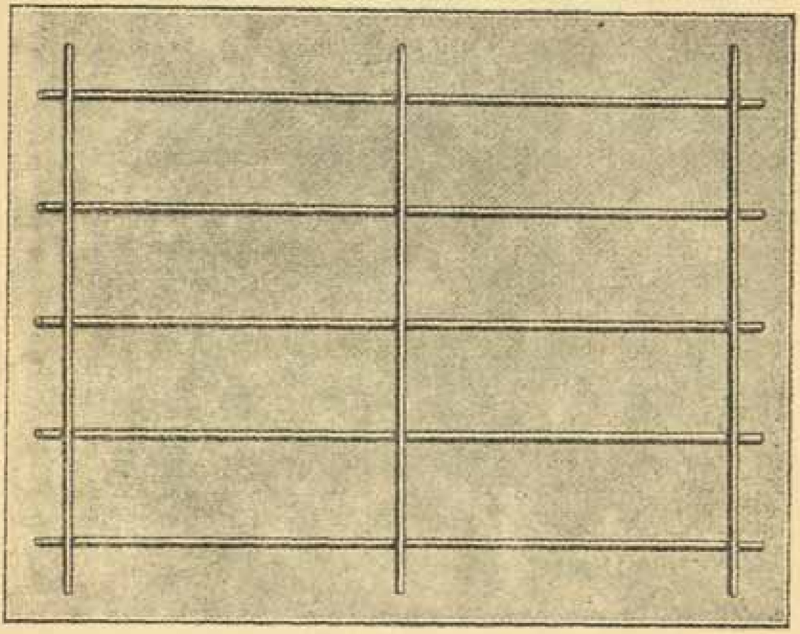


Fig. 1-7. B. R. C. Fabric.

(i) *B.R.C. Fabric*: is made from hard-drawn steel wire and consists of a wire mesh made up of a series of parallel longitudinal wires held at fixed distances apart by means of transverse wires at right angles to longitudinal wires (See Fig. 1-7). A higher working tensile strength of 25,000 lbs. per sq. inch is recommended by the manufacturers. Properties of standard sizes of B.R.C. Fabric are given in the following table. The Fabric is available in sheets 7 ft. wide.

Ref. No. of Fabric	Size of Mesh and or Wire					Weight Lbs./□ yd.
	Distance of Longitudinal Wires Inches	Distance of Cross Wires Inches	Gauge of Wire (Imperial)		Sectional Area Per Ft. Width Sq. In.	
			Longitudinal	Cross		
1	3	16	4/0	4	.5028	16.23
2	"	"	3/0	4	.4348	14.15
3	"	"	2/0	6	.3804	12.22
4	"	"	1/0	6	.3296	10.67
5	"	"	1	6	.2828	9.31
6	3	16	2	7	.2392	7.78
7	"	"	3	8	.1996	6.56
8	"	12	4	9	.1692	5.66
9	"	"	5	10	.1412	4.81
10	"	"	6	10	.1160	3.92
11	3	12	7	10	.0972	3.37
12	"	"	8	12	.0804	2.71
13	"	"	9	12	.0652	2.25
14	"	"	10	12	.0516	1.83
65	6	6	5	5	.0706	4.32
610	6	6	10	10	.0258	1.57

(ii) *Maxweld Fabrics*: These are also of the same type as B.R.C. and their references Nos. 403, 303, 203, 103, 1, 2, 3, 4, 5B, 6, 7, 8, 9, 10, 56 and 106 correspond approximately with Reference Nos. 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 65 and 610 of B.R.C. fabrics.

Fabrics Nos. 3, 4 and 5 are not very common in this country and hence particulars of the same have not been given.

(e) *Expanded Steel*: This is made from steel plates and sheets by cutting them and expanding them into diamond-shaped meshes of different sizes. Manufacture is controlled by B.S.S. 1221, Part C, main requirements being:

The blank steel plates shall have ultimate stress between 26 to 32 tons per sq. inch.

The strength of the fabric shall be—

Minimum ultimate tensile stress	75,000 lbs. per sq. in.	
,, yield stress	50,000 ,,	,,
,, elongation	$7\frac{1}{2}\%$	

Due to absence of any joints in the mesh work the fabric can be stressed to 20,000 lbs. per sq. inch in design work.

(f) *Ribbed Mesh Steel Sheets* (*See Fig.* 1-8) : The 'V' shaped ribs give rigidity to the fabrics and the meshwork is so shaped that it retains the wet concrete without appreciable loss of the same through the openings. Only timber joists are required for supporting the fabric at definite intervals depending upon the thickness of slab. This type of reinforcement is very convenient and economical in case of curved surfaces

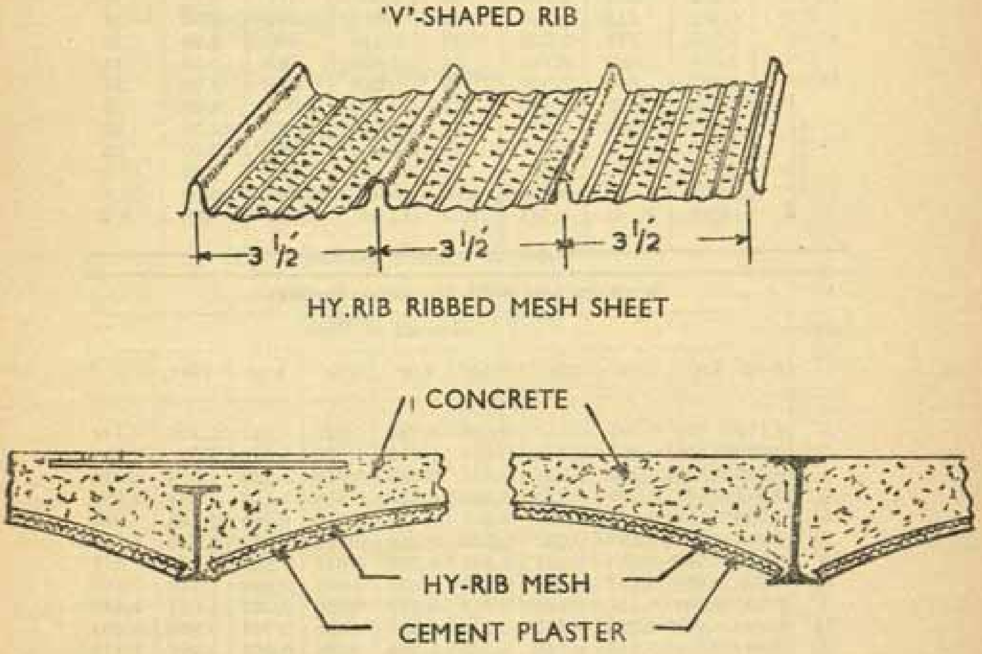


Fig. 1-8.

where shuttering cost is heavy (see Fig. 1-8). "Hyrib" and "Self-sentering" are two common trade names for such reinforcement available in this country in pre-war days.

1.4.4 AREAS, WEIGHTS, ETC. OF BARS.

Round and Square M. S. Bars.

Weight in pounds per Lineal foot. Area in sq. inches and Perimeters in inches.

Diameter or Side in inches	Round ●				Square. ■			
	Weight	Area	Perimeter	Lineal feet in 1 cwt.	Weight	Area	Perimeter.	Lineal feet in 1 cwt.
3/16	.094	.027	.589	1192	.120	.035	.75	933
1/4	.167	.049	.785	667	.213	.062	1.00	526
5/16	.261	.076	.982	428	.332	.097	1.25	337
3/8	.376	.110	1.178	297	.478	.140	1.50	234
7/16	.511	.150	1.375	218	.651	.191	1.75	172
1/2	.669	.196	1.571	167	.849	.250	2.00	132
9/16	.845	.248	1.767	132	1.076	.316	2.25	104
5/8	1.043	.306	1.963	107	1.328	.390	2.50	84
11/16	1.262	.371	2.160	88	1.607	.472	2.75	70
3/4	1.502	.442	2.336	74	1.912	.562	3.00	59
12/16	1.763	.518	2.553	63	2.245	.660	3.25	50
7/8	2.044	.601	2.749	54	2.653	.765	3.50	43
15/16	2.347	.690	2.945	45	2.988	.879	3.75	37
1	2.670	.785	3.142	42	3.400	1.000	4.00	33
$1\frac{1}{8}$	3.380	.994	3.534	33	4.343	1.265	4.50	26
$1\frac{1}{4}$	4.172	1.227	3.927	27	5.312	1.562	5.00	22
$1\frac{3}{8}$	5.049	1.485	4.320	22	6.428	1.820	5.50	17.5
$1\frac{1}{2}$	6.008	1.767	4.713	18.5	6.650	2.250	6.00	15.6
2	10.68	3.141	6.283	10.5	13.60	4.000	8.00	8.2

Areas per foot width for various Spacings.

Spacing	Diameter of Bars.									
	3/16"	1/4"	5/16"	3/8"	7/16"	1/2"	5/8"	3/4"	7/8"	1"
3"	0.110	0.196	0.307	0.442	0.601	0.785	1.227	1.767	2.405	3.142
$3\frac{1}{2}$"	0.095	0.168	0.263	0.379	0.515	0.673	1.052	1.515	2.06	2.69
4"	0.083	0.147	0.230	0.331	0.451	0.589	0.930	1.325	1.804	2.356
$4\frac{1}{2}$"	0.074	0.131	0.205	0.295	0.401	0.524	0.818	1.178	1.604	2.09
5"	0.066	0.118	0.184	0.265	0.361	0.471	0.736	1.060	1.443	1.885
$5\frac{1}{2}$"	0.060	0.107	0.167	0.241	0.328	0.428	0.669	0.964	1.312	1.714
6"	0.055	0.098	0.153	0.221	0.301	0.393	0.614	0.884	1.203	1.571
$6\frac{1}{2}$"	0.051	0.091	0.142	0.204	0.278	0.365	0.566	0.816	1.110	1.450
7"	0.047	0.084	0.131	0.189	0.258	0.337	0.526	0.797	1.631	1.346
$7\frac{1}{2}$"	0.044	0.079	0.123	0.177	0.241	0.314	0.491	0.707	0,962	1.257
8"	0.041	0.074	0.115	0.166	0.225	0.295	0.461	0.663	0.902	1.178
$8\frac{1}{2}$"	0.039	0.069	0.108	0.156	0.212	0.227	0.433	0.624	0.849	1.109
9"	0.037	0.065	0.102	0.147	0.200	0.262	0.409	0.589	0.802	1.047
$9\frac{1}{2}$"	0.035	0.062	0.097	0.140	0.190	0.248	0.388	0.586	0.760	0.992
10	0.033	0.059	0.092	0.139	0.180	0.236	0.368	0.530	0.722	0.942
$10\frac{1}{2}$"	0.032	0.056	0.088	0.126	0.172	0.224	0.351	0.505	0.687	0.898
11"	0.030	0.054	0.084	0.120	0.164	0.214	0.335	0.482	0.656	0.857
12"	0.028	0.049	0.077	0.110	0.150	0.196	0.307	0.442	0.501	0.785
15"	0.022	0.039	0.061	0.088	0.120	0.157	0.245	0.359	0.481	0.628
18"	0.018	0.039	0.051	0.074	0.100	0.131	0.205	0.295	0.401	0.524
24"	0.014	0.025	0.038	0.055	0.075	0.098	0.153	0.221	0.301	0.399

CHAPTER 2

PROPORTIONING OF CONCRETE

CONTENTS

CHAPTER 2

PROPORTIONING OF CONCRETE

2.1 INTRODUCTORY NOTES.

2.1.1 INTRODUCTION.

Concrete is a mixture of cement, water and aggregates, which consolidates into a hard mass due to chemical reaction between cement and water. Each of the four ingredients has its separate function. Coarse aggregates act as main filler. Fine aggregates fill in the voids in the coarse aggregates and cement and water form the binder. The science of proportioning of concrete is therefore mainly concentrated on the principle of obtaining a durable and strong concrete at the most economical rate. It is obvious that a properly designed concrete mix for certain requirements of strength should have the minimum possible cement content to make the mix economical.

2.1.2 WATER CEMENT RATIO.

The ratio of weight or volume of water used for mixing (correction of absorption by aggregates should be made), to weight or volume of cement in the concrete mixture. It may also be expressed as so many gallons of water per cwt. of cement. Since volume of cement is a variable term depending upon the manner in which a volumetric measure is filled, it is preferable always to express the water cement ratio on weight basis. Prof. D. Abrams discovered that the strength of concrete is solely governed by the amount of water used in making the concrete and is independent of the ratio of cement to aggregates provided the concrete is workable. The results of thousands of experiments carried out by him with various cement aggregate ratios are shown in Fig. 2-1 from which it will be noted that mixes varying from neat cement to 1:15 give the same strength. The equation of the curve is:—

$$S = \frac{A}{B^x} \text{ or } \log S = \log A - x \log B$$

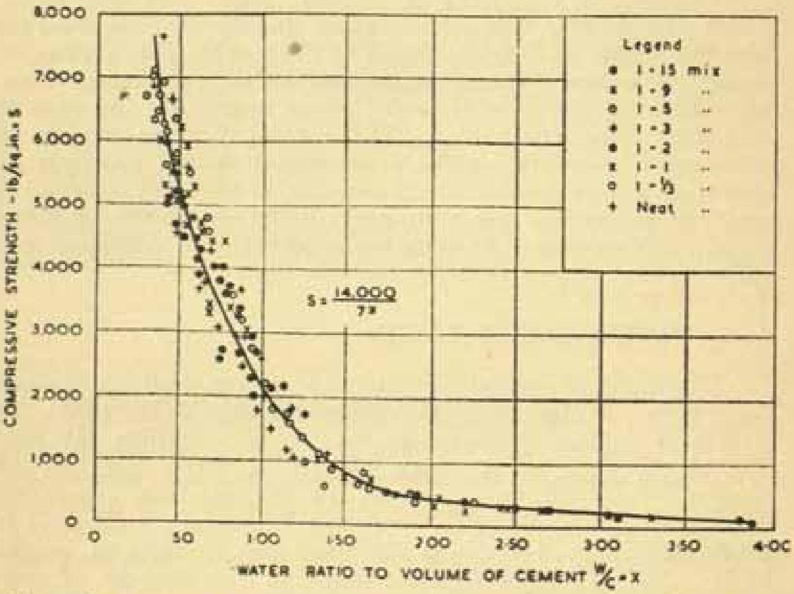
S = compressive strength in lbs.|sq. inch.

$$X = \frac{\text{Volume of mixing water}}{\text{Volume of cement}}$$

(Note.—1 cft. of cement is assumed to weigh 94 lbs.)

A and B are constants depending upon age of concrete, quality of cement and aggregates, climatic conditions, mixing, etc.

For washed and graded gravel, workable mix mixed in a machine for one minute, the values of A and B are: $A = 14000$ and $B = 9$ for 28 days strength (for special control $B = 7$).



Note: Lean and Rich Mixtures give same strength for same W/c Ratio. The figures represent Cylinder strengths which are ⅘ the corresponding cube strengths.

Fig. 2–1.

It should be noted that though the water cement ratio law holds good universally the values of the constants A and B may vary according to the quality of cement, aggregates, etc. The values of compressive strength as given in curve in Fig. 2-1 are low, compared to present day values, as there is considerable progress in the manufacture of cement. The following values should therefore be used. Where the magnitude of the job permits the values of the constants should be found by actual experiments.

Water Cement Ratio			Crushing Strength Lbs/□" @ 7 days	Remarks
Gals/cwt.	By Wt.	By volume		
4	.36	.52	5600	mix too dry for hand compaction
4½	.40	.58	4950	
5	.45	.64	4300	
5½	.49	.71	3750	
6	.54	.77	3250	mix workable for hand compaction
6½	.58	.84	2850	
7	.63	.90	2400	
7½	.67	.97	2120	
8	.71	1.03	1850	
8½	.76	1.10	1670	Wet mix
9	.80	1.16	1500	

(Note.—The figures are for cube test.)

2.1.3 WORKABILITY.

Has been defined in the simplest form as ease with which concrete can be mixed, handled, transported and placed. Workability will therefore vary according to the type of mould that is being used for the concrete structure under construction and the obstruction to the free flow of concrete caused by the spacing and nature of the reinforcement. Rational measure of workability is therefore not easy. A more scientific definition of workability would therefore be that property of concrete which determines the amount of useful internal work required to produce full compaction.

MEASUREMENT OF WORKABILITY.

(*a*) *Slump Test* : is very widely used. Sometimes, however, accurate results are not possible by this test due to distorted slumps as shown in figure below. (Fig. 2-2.)

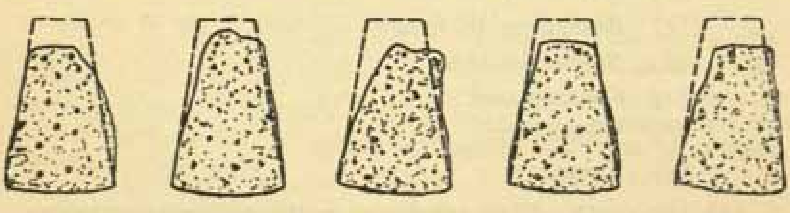
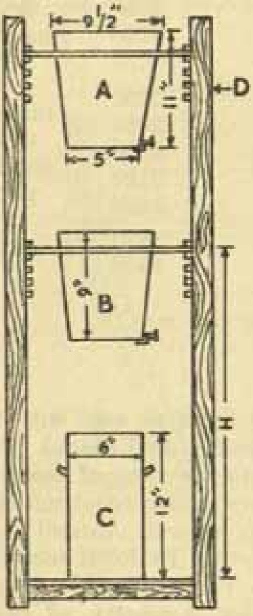


Fig. 2-2. Distorted Slump.

(b) *Compacting Factor Test.*—It is a better test and depends on the definition of workability on basis of internal work as mentioned above. Concrete is made to fall into a mould from a standard height so that it compacts itself by gravity. Apparatus used is shown below. (Fig. 2-3.)



The height H determines the workability. The hopper (B) is not filled directly with concrete but by means of another hopper. (A). The heights of the hoppers can be varied as desired.

Fig. 2-3. Compaction Test.

(A) Top Hopper (with hinged bottom).
(B) Main ,, ,,
(C) Mould.
(D) Wooden Stand

2.2 ESSENTIAL REQUIREMENTS.

These are:—

(a) Strength.
(b) Durability.
(c) Resistance to wear.
(d) Water-tightness.
(e) Compactness.
(f) Workability.
(g) Economy.

(a) *Strength.*—The capacity to withstand without injury the stresses developed when being used as a structural material.

(b) *Durability.*—The property of resisting the action of chemical and physical destructive agents, such as—

(i) Leaching due to lime contents in the cement being dissolved by pure and distilled waters.

(ii) Expansion and contraction resulting from temperature and alternate drying and wetting.

(iii) Freezing and thawing of water sucked in small crevices by capillary action.

(iv) Disintegration by alkaline, acidic or saline waters.

(c) *Resistance to wear.*—Especially in case of pavements and roads.

(d) *Water-tightness.*—Obstructing through passage of water after initial absorption takes place.

(e) *Compactness.*—Is the proportion between the volume of concrete produced and the absolute volume of the aggregates and cement used.

(f) *Workability.*—Ease with which concrete can be handled, transported and placed.

(g) *Economy.*—Is effected by using local aggregates with minimum amount of cement and designing the mix properly to get the specified strength.

2.3 PROPORTIONING OF CONCRETE.

Various methods of proportioning are:—

2.3.1 ARBITRARY PROPORTIONS.

The proportions of cement, sand and coarse aggregates are specified as 1 : 2 : 4; 1 : 3 : 6, etc., mostly by volume.

2.3.2 SIMPLE VOIDS METHOD.

Voids in the coarse aggregates are to be filled in by the sand and voids in sand are to be filled in by cement paste. Ten per cent extra sand and 15 per cent extra cement paste are provided to allow for additional voids created by wedging action of sand particles on the coarse aggregates and that of cement particles on the sand.

Example.—Design a concrete mix if coarse aggregates and sand have 43% and 32% voids respectively.

Sand required for 100 cft. of coarse aggregate
$=43+.43\times10=47.3$ cft.

Cement paste required
$=(47.3\times.32)+(47.3\times.32\times.15)=17.406$ cft.

$\therefore$ Dry cement required$=17.406\times1.2=20.9$ cft.
$=20.9$ cft.

$\therefore$ Proportions of cement: sand: coarse aggregate
$= 20.9 : 47.3 : 100$
$= 1 : 2.31 : 4.9$

2.3.3 FINENESS MODULUS METHOD.

2.3.3.1 Object.

The arbitrary mix method described earlier in para 2.3.1 has certain drawbacks, as the exact strength of the arbitrary mix is not known and such mixes are usually uneconomical. It is, therefore, necessary to specify concrete of a stipulated strength, and to work out an economical mix by some rational method. The following paras explain in a simple manner the convenient methods which may be adopted with advantage.

2.3.3.2 Variables in design of concrete mix.

The variables in the design of a mix are:

(a) Water-cement ratio.
(b) Cement content for a unit quantity of concrete.
(c) Workability, grading of aggregates, and proportions of fine and coarse aggregates.

2.3.3.3 Data required for designing a concrete mix.

It is necessary to ascertain the following data before designing a satisfactory concrete mix.

The minimum compressive strength of concrete to which a structure is designed is essential, and the workability required is also necessary. As use has to be made of available aggregate, the grading of both coarse and fine aggregates, their weights, their bulking percentage and the water content must be known. These can be easily determined.

2.3.3.4 Relation between the minimum and average crushing strength.

Table 1 gives the estimated relation between the minimum and average crushing strength of works cubes for different conditions.

This serves as a guide for determining the average strength on which the mix design is to be based when the minimum strength is specified.

2.3.3.5 Water-Cement Ratio.

Table 2 gives the relation between the crushing strength and water-cement ratio for fully compacted concrete using ordinary Portland cement. The water-cement ratio is determined for the average strength.

2.3.3.6 Workability and Slump.

The degrees of workability for various requirements are given in Table 3, and knowing the conditions of work, the required slump is determined from this table.

2.3.3.7 Weight of cement per 100 c.ft. of concrete.

The quantity of cement per 100 cft. of concrete may be determined from Table 4 in which the total quantity of water per 100 cft. of concrete is given. These values divided by the water-cement ratio give the required quantity of cement.

2.3.3.8 Absolute volumes of water, cement and mixed aggregates.

The quantity of water and of cement per 100 cft. of concrete being found, the absolute volumes of these two are obtained by dividing the weights by their absolute specific gravities. The absolute volume of mixed aggregate is then 100 minus absolute volumes of water and cement. The absolute specific gravities for cement, fine and coarse aggregates may be taken as 3.15, 2.65 and 2.55 respectively.

2.3.3.9 Determination of fineness modulii of fine and coarse aggregates and calculation of the proportions of fine and coarse aggregates.

The proportions of coarse and fine aggregates to produce optimum workability is obtained through Fineness Modulus. The fineness modulii of the coarse and of the fine aggregates are determined separately by ascertaining the percentage retained on each of the sieves.

100—52—25—14—7 — 3/16″—3/8″—¾″—1½″—3″

The sum of the percentages retained divided by 100 gives the F.M. Suitable F.M. for mixed aggregates are given in Table 5. The percentage of fine aggregate is obtained from $\frac{F_c - F_m}{F_c - F_f} \times 100$. Values of F_c and F_f i.e. the F.M. of coarse and fine aggregates respectively, are determined as above and the value of F_m, the F.M. for mixed aggregate, is taken from Table 5.

2.3.3.10 Absolute volumes and weights of fine and coarse aggregates.

Once the proportions of coarse and fine aggregates are determined as explained, the absolute volumes of these aggre-

gates are obtained from these proportions. The weights of the aggregates are determined by multiplying the absolute volumes by absolute specific gravity and the weight of water.

2.3.3.11. Determination of the Nominal Mix.

The nominal mix is obtained by dividing the weights of the various components by the weight of cement.

2.3.3.12 Quantity of mixing water required.

In order to determine the quantity of mixing water required per 100 cft. of concrete, the free moisture in the aggregates has to be taken into account; the free moisture being obtained by multiplying the percentage of water in each aggregate by the weight required for 100 cft. of concrete. This free moisture is to be deducted from the total quantity of mixing water as determined in para 2.3.3.5.

2.3.3.13. Field Mix by Weight.

The field mix by weight is obtained by taking into consideration the free moisture in the aggregates in the nominal mix.

2.3.3.14. Field Mix by Volume.

It is often convenient to prepare a concrete mix by volume, and in such a case, bulking of the aggregates has to be taken into consideration. Bulking is the increase in volume of aggregates due to the presence of water. The method of correction for this item is shown in the example.

2.3.3.15 Quantity of mixing water required per bag of cement.

The mixing water required after allowing for the free moisture in the aggregates is easily obtained by dividing the mixing water as obtained in para 2.3.3.12 by the number of bags of cement required per 100 cft. of concrete as determined in para 2.3.3.7.

TABLE 1

Estimated relation between the Minimum and Average Crushing strengths of works cubes for different works conditions.

Conditions	Minimum strength as percentage of average strength.
Very good control with weight batching, constant supervision,etc.	75
Fair control	60
Poor Control	40

TABLE 2

Relation between Cube Crushing Strength and Water-Cement Ratio by weight for Fully Compacted Concrete (Ordinary Portland Cement).

Water-cement ratio by weight	Cube crushing strength p.s.i. 7 days	28 days
0.35	5,700	7,500
0.40	5,000	6,700
0.45	4,300	6,000
0.50	3,600	5,300
0.55	3,100	4,600
0.60	2,600	4,000
0.65	2,200	3,500
0.70	1,900	3,100
0.75	1,600	2,800
0.80	1,500	2,500

NOTES: 1. Cylinder strength may be taken as 0.8 of cube strength.
2. Strengths at 3 months and 1 year are approximately 25% and 67% greater than the strength at 28 days.

TABLE 3.

Degrees of workability for various requirements.

Degree of workability	Slump in inches	Use for which concrete is suitable.
"Very Low"	0 to 1	Vibrated concrete in roads or other large sections.
"Low"	1 to 2	Mass concrete foundation without vibration. Simple reinforced sections with vibration.
"Medium"	2 to 4	For normal reinforced work without vibration and heavily reinforced sections with vibration.
"High"	4 to 7	For sections with congested reinforcement. Not normally suitable for vibration.

TABLE 4.

Water content per 100 cft. of concrete for 3″ slump.

Max. size of coarse aggregate	½″	¾″	1″	1½″	2″	3″
Water in lbs.						
(a) for rounded coarse aggregate	1241	1149	1111	1037	982	926
(b) for angular coarse aggregate	1333	1241	1204	1122	1074	1019

For each 1″ increase or decrease in slump, increase or decrease the water content by 3 percent.

TABLE 5.

Fineness Modulii of mixed aggregates for different sizes of aggregates.

Max. size of coarse aggregate.	½″	¾″	1″	1½″	2″	3″
Fineness Modulii of mixed aggregate.						
Min.	4.5	4.8	5.0	5.4	5.7	5.9
Max.	5.0	5.3	5.5	6.0	6.3	6.5

EXAMPLE

(Paragraph numbers in this example are identical with the paragraph numbers in the text of section 2.3.3)

3. Data

 3.1 Minimum compressive strength—750 lbs. per sq. in.

 3.2 Workability—Medium

 3.3 Aggregates available

3.3.1 Coarse aggregates	¾″ gravel (rounded coarse aggregate) with 40% passing ⅜″ sieve.
Weight of C.A.	90 lbs. per c.ft.
Bulking percentage	2.56
Water content	1%

3.3.2 Fine aggregates	% passing	100	sieve	2
	,,	52	,,	10
	,,	25	,,	45
	,,	14	,,	67
	,,	7	,,	87
	,,	3/8	,,	100
Weight of F. A.	100 lbs. per c. ft.			
Bulking percentage	14.3			
Water content	2%			
3.4 Control	Fair			

4. Average crushing strength $= \frac{750 \times 3}{0.6}$ (Refer Table 1)

$= 3{,}750$ p.s.i.

Note :—Cube strength should be 3 times working strength.

5. Water-Cement Ratio = 0.62 (Refer Table 2)

6. Slump required = 3" (Refer Table 3)

7. Determination of the weight of cement per 100 cft. of concrete.

Weight of cement per 100 cft. of concrete $= \dfrac{\text{Total quantity of water per 100 cft. of concrete.}}{\text{Water-cement Ratio}}$ (Refer Table 4)

$= \frac{1149}{0.62}$

$= 1853$ lbs.

8. Absolute volumes of water, cement and mixed aggregates.

8.1 Absolute volume of water $= \frac{1149}{62.4} = 18.4$

8.2 Absolute volume of cement $\frac{1853}{3.15 \times 62.4} = 9.4$

Absolute volume of water and cement $= 18.4 + 9.4 = 27.8$ c.ft.

8.3 Therefore, absolute volume of mixed aggregates $= 100 - 27.8 = 72.2$ c.ft.

9. F.M. of fine and coarse aggregates and proportions of fine and coarse aggregates.

9.1 F.M. of coarse aggregates=Fc

Sieve	*Passing*	*Retained*
3/8"	40%	60%
3/4"	100%	0%
3/16"	0%	100%
7	0%	100%
14	0%	100%
25	0%	100%
52	0%	100%
100	0%	100%
		660%

$$Fc = \frac{660}{100} = 6.6$$

9.2 F.M. of fine aggregates = Ff

Sieve	*Passing*	*Retained*
100	2	98
52	10	90
25	45	55
14	67	33
7	87	13
3/16"	100	0
		289

$$Ff = \frac{289}{100} = 2.89$$

9.3 Average F.M. of mixed aggregates = 5.05 (Refer Table 5)

9.4 % of fine aggregate $= \frac{F_c - F_m}{F_c - F_f} \times 100 = \frac{6.6 - 5.05}{6.6 - 2.89} \times 100$
$= 42$

9.5 % of coarse aggregate = 100 — 42 = 58%

10. Absolute volumes and weights of fine and coarse aggregates.

10.1 Absolute volume of fine aggregate = $72.2 \times .42 = 30.3$

10.2 Absolute volume of coarse ,, = $72.2 \times .58 = 41.9$

10.3 Therefore, weight of fine aggregate per 100 c.ft. of concrete = $30.3 \times 2.65 \times 62.4$ = 5012 lbs.

10.4 And weight of coarse aggregate per 100 c.ft. of concrete = $41.9 \times 2.55 \times 62.4$ = 6666 lbs.

11. Nominal Mix

$$\text{Nominal mix} = \frac{1853}{1853} : \frac{5012}{1853} : \frac{6666}{1853}$$
$$= 1 : 2.7 : 3.6$$

12. Mixing water required per 100 c.ft. of concrete

Water content of F.A. $= 5012 \times .02 = 100$ lbs.
Water content of C.A. $= 6666 \times .01 = 66$ lbs.
Total water content of F.A. and C.A. $= 166$ lbs.
Hence mixing water required $= 1149 - 166 = 983$ lbs.
$= 98.3$ gallons

per 100 c.ft. of concrete after allowing for moisture in the aggregate.

13. Field Mix by Weight (taking into consideration weight of water in aggregates)

$$= \frac{1853}{1853} : \frac{5012+100}{1853} : \frac{6666+66}{1853}$$
$$= 1 : 2.76 : 3.63$$

14. Field Mix by Volume (taking into consideration bulking of materials).

$$\text{Volume of cement in bags} = \frac{1853}{112} = 16.6 \text{ bags}$$

Volume of F.A. allowing for bulking
$$= \frac{\text{weight of F.A. per 100 c.ft. of concrete.}}{\text{weight of F.A. per c.ft.}} \left(\begin{matrix}1+\text{bulking per-}\\ \text{centage of F. A.}\end{matrix}\right)$$
$$= \frac{5012}{100}\left(1 + \frac{14.3}{100}\right)$$
$$= 57.3 \text{ c.ft.}$$

Volume of C.A. after allowing for bulking
$$= \frac{\text{weight of C.A. per 100 c.ft. of concrete}}{\text{weight of C.A. per c.ft.}} \left(\begin{matrix}1+\text{bulking per-}\\ \text{centage of C. A.}\end{matrix}\right)$$
$$= \frac{6666}{90}\left(1 + \frac{2.56}{100}\right)$$
$$= 76 \text{ c.ft.}$$

Field Mix by volume is therefore

$$\frac{16.6}{16.6} : \frac{57.3}{16.6} : \frac{76}{16.6}$$

= 1 bag cement : 3.5 c.ft. sand : 4.6 c.ft. coarse aggregate.

15. Quantity of mixing water required per bag of cement after allowing for moisture in the aggregates

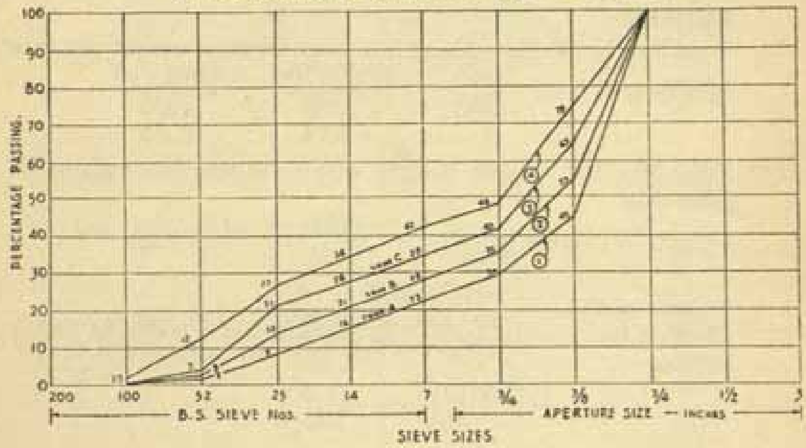
$$= \frac{98.3}{16.6} = 5.9 \text{ gallons}$$

2.3.4 GRADING CURVES METHOD OF PROPORTIONING.

2.3.4.1 In this method, the average crushing strength, water-cement ratio and the degree of workability are determined as in the previous method, use being made of Tables 1, 2 and 3.

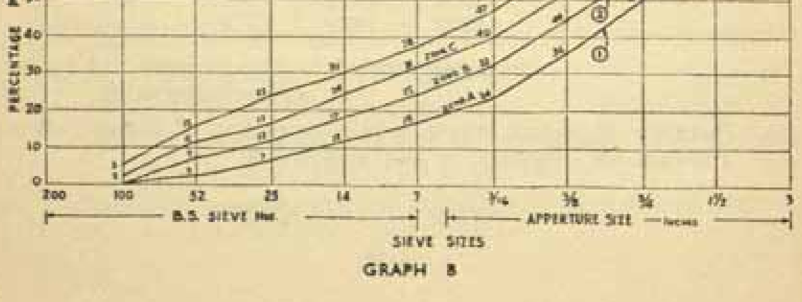
2.3.4.2 The aggregate-cement ratio is obtained from Table 6. These ratios are given for $\frac{3}{4}''$ and $1\frac{1}{2}''$ aggregates and for four different gradings in each case, as depicted in graphs Nos. A and B.

CURVES OF FOUR GRADINGS OF 3/4-IN. AGGREGATE



GRAPH A

CURVES OF FOUR GRADING OF 1½-IN. AGGREGATE



GRAPH B

2.3.4.3 Suitable proportions of fine and coarse aggregates are determined from these graphs as illustrated in the second Example.

2.3.4.4 The nominal mix is read off from the results obtained in preceding para 2.3.4.3.

2.3.4.5 The field mix by weight is obtained by multiplying the nominal mix proportions by the weight of a bag of cement and adding the weight of free moisture.

2.3.4.6 The quantity of mixing water is obtained by multiplying the water-cement ratio by the weight of a bag of cement and deducting the free moisture in the aggregates.

2.3.4.7 The field mix by volume is obtained in the same way as in para 2.3.3.14.

The limitation of this method is that aggregate-cement ratio Tables are available for ¾″ and 1½″ aggregates only at present.

Table 6 and graphs A and B are taken from the U.K. Road Research Institute Brochure No. 4 on "Design of Concrete Mixes", and Tables 1, 2 and 3 are based on data given in the same brochure.

TABLE NO. 6 Aggregate-Cement Ratio Required to give Four Degrees of Workability with different gradings and types of aggregate.

(A) ¾ in. Rounded Aggregate.

Degree of Workability	Very Low				Low				Medium				High			
Grading of aggregate Curve No. on Graph A	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Water-cement ratio by weight																
0.35	4.5	4.5	3.5	3.2	3.8	3.6	3.2	3.1	3.1	3.0	2.8	2.7	2.8	2.8	2.6	2.5
0.40	6.6	6.3	5.3	4.5	5.3	5.1	4.5	4.1	4.2	4.2	3.9	3.7	3.6	3.7	3.5	3.3
0.45	8.0	7.7	6.7	5.8	6.9	6.6	5.9	5.1	5.3	5.3	5.0	4.5	4.6	4.8	4.5	4.1
0.50			8.0	7.0	8.2	8.0	7.0	6.0	6.3	6.3	5.9	5.4	5.5	5.7	5.3	4.8
0.55				8.1			8.2	6.9	7.3	7.3	7.4	6.4	6.3	6.5	6.1	5.5
0.60								7.7			8.0	7.2		7.2	6.8	6.1
0.65								8.5				7.8		7.7	7.4	6.6
0.70															7.9	7.2
0.75																7.6
0.80																
0.85																
0.90																

TABLE NO. 6 (B) ¾ in. Irregular Gravel Aggregate.

Degree of Workability.	Very Low				Low				Medium				High			
Grading of aggregate (Curve No. on Graph A	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
0.35	3.7	3.7	3.5	3.0	3.0	3.0	3.0	2.7	2.6	2.6	2.7	2.4	2.4	2.5	2.5	2.2
0.40	4.8	4.7	4.7	4.0	3.9	3.9	3.8	3.5	3.3	3.4	3.5	3.2	3.1	3.2	3.2	2.9
0.45	6.0	5.8	5.7	5.0	4.8	4.8	4.6	4.3	4.0	4.1	4.2	3.9		3.9	3.9	3.5
0.50	7.2	6.8	6.5	5.9	5.5	5.5	5.4	5.0	4.6	4.8	4.8	4.5		4.4	4.4	4.1
0.55	8.3	7.8	7.3	6.7	6.2	6.2	6.0	5.7		5.4	5.4	5.1		4.8	4.9	4.7
0.60	9.4	8.6	8.0	7.4	6.8	6.9	6.7	6.2		6.0	6.0	5.6			5.4	5.2
0.65				8.0	7.4	7.5	7.3	6.8			6.4	6.1			5.8	5.6
0.70					8.0	8.0	7.7	7.4			6.8	6.6			6.2	6.1
0.75								7.9			7.2	7.0			6.6	6.5
0.80											7.5	7.4				7.0
0.85											7.8	7.8				7.4
0.90												8.1				7.7
0.95																8.0
1.00																

Water-cement ratio by weight.

TABLE No. 6 (C) ¾ in. Crushed Rock Aggregate.

Degree of Workability		Very Low				Low				Medium				High			
Grading of aggregate (Curve No. on Graph A)		1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Water-cement ratio by weight.	0.35	3.2	3.0	2.9	2.7	2.7	2.7	2.5	2.4	2.4	2.4	2.3	2.2	2.2	2.3	2.1	2.1
	0.40	4.5	4.2	3.7	3.5	3.5	3.5	3.2	3.0	3.1	3.1	2.9	2.7	2.9	2.9	2.8	2.6
	0.45	5.5	5.0	4.6	4.3	4.3	4.1	3.9	3.7	3.7	3.7	3.4	3.3	3.5	3.5	3.2	3.1
	0.50	6.5	5.8	5.4	5.0	5.0	4.9	4.5	4.3	4.2	4.2	3.9	3.8		3.9	3.8	3.5
	0.55	7.2	6.6	6.0	5.6	5.7	5.4	5.0	4.8	4.7	4.7	4.5	4.3			4.3	4.0
	0.60	7.8	7.2	6.6	6.3	6.3	6.0	5.6	5.3		5.2	4.9	4.8			4.7	4.4
	0.65	8.3	7.8	7.2	6.9	6.9	6.5	6.1	5.8		5.7	5.4	5.2			5.1	4.9
	0.70	8.7	8.3	7.7	7.5	7.4	7.0	6.5	6.3		6.2	5.8	5.7			5.5	5.3
	0.75			8.2	8.0	7.9	7.5	7.0	6.8			6.2	6.1			5.8	5.7
	0.80							7.4	7.2			6.6	6.5			6.1	6.0
	0.85							7.8	7.6			7.1	6.9			6.4	6.3
	0.90											7.5	7.3				6.7
	0.95											8.0	7.6				7.0
	1.00																7.3

TABLE NO. 6 (D) 1½ in. Irregular River Gravel Aggregate.

Degree of Workability.	Very Low				Low				Medium				High			
Grading of aggregate Curve No. on Graph B)	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Water-cement ratio by weight. 0.35	4.0	3.9	3.5	3.2	3.4	3.3	3.2	2.9	2.9	2.8	2.6	2.5	2.7	2.5	2.3	2.3
0.40	5.3	5.3	4.7	4.3	4.5	4.5	4.2	3.8	3.8	3.8	3.7	3.4	3.5	3.5	3.3	3.1
0.45	6.5	6.5	5.9	5.3	5.6	5.6	5.3	4.8	4.6	4.7	4.6	4.3	4.1	4.4	4.3	4.0
0.50	7.7	7.7	7.1	6.3	6.7	6.6	6.3	5.7	5.4	5.7	5.5	5.1	4.8	5.2	5.1	4.8
0.55			8.1	7.3	7.6	7.6	7.2	6.6	6.2	6.5	6.3	5.8		5.9	6.0	5.5
0.60								7.4	7.0	7.3	7.1	6.6			6.7	6.2
0.65								8.1	7.8	8.1	7.8	7.2			7.3	6.9
0.70												7.9				7.4
0.75																8.0
0.80																

EXAMPLE

(Paragraph numbers in this example are identical with the paragraph numbers in the text of section 2.3.4.)

2.3.4.1 Data.

Minimum compressive strength	750 lbs. per sq. in.
Workability—Medium.	
Aggregates available :	
Coarse aggregates	$\frac{3}{4}''$ gravel (rounded coarse aggregate) with 40% passing $\frac{3}{8}''$ sieve.
Weight of C.A.	90 lbs. per cft.
Bulking percentage	2.56
Water content	1%
Fine aggregates	% passing 100 sieve 2
	,, 52 ,, 10
	,, 25 ,, 45
	,, 14 ,, 67
	,, 7 ,, 87
	,, $\frac{3}{8}$,, 100
Weight of F.A.	100 lbs. per c.ft.
Bulking percentage	14.3
Water content	2%
Control	Fair
Average crushing strength	$=\frac{750 \times 3}{0.6}$ (Refer Table 1) $=3{,}750$ p.s.i

Note :—Cube strength should be 3 times working strength.

Water-cement Ratio	=0.62	(Refer Table 2)
Slump required	=3″	(Refer Table 3)

2.3.4.2 Aggregate-Cement Ratio:

For a medium workability and w/c ratio of .62, two different aggregate-cement ratios are obtained from Table 6 as follows, irregular gravel being assumed:

For grading No. 3	....	6.2
,, ,, No. 4	....	5.8

For an economic mix, the aggregate-cement ratio must be as high as possible, i.e., in this case, our grading should approximate to standard grading No. 3 (please refer to graph A).

2.3.4.3 Proportions of Fine and Coarse Aggregates:

The following three trial mixes are prepared:

	Sand	Coarse Aggregate
A	30%	70%
B	35%	65%
C	40%	60%

The sieve analysis of these three mixes is determined and the results are as follows:—

B.S. Sieve	Percentage of material passing sieve		
	Sample containing 30% sand	Sample containing 35% sand	Sample containing 40% sand
No. 100	0.6	0.7	0.7
,, 52	3.0	3.5	4.0
,, 25	13.5	15.75	18.0
,, 14	20.5	23.4	26.8
,, 7	26.0	30.4	34.8
3/16 in.	30.0	36.0	40.0
3/8 in.	58.0	60.0	64.0
3/4 in.	100.0	100.0	100.0

Curves of these gradings are drawn on a tracing paper to the same scale as the optimum grading curves in graph A.

This tracing paper is superimposed on the optimum grading curves to ascertain which of the above three mixes approximates to optimum grading No. 3.

In this case, mix C approximates to optimum grading No. 3, hence, the mix containing 40% sand is suitable.

Hence proportion of sand $= 6.2 \times \frac{40}{100} = 2.48$

and ,, of coarse aggregate $= 6.2 \times \frac{60}{100} = 3.72$

2.3.4.4 Nominal Mix.

Therefore the nominal mix = 1 : 2.48 : 3.72
say = 1 : 2.5 : 3.7

2.3.4.5 Field Mix by Weight.

The quantities of materials required by weight are:

Cement	=112 lbs.	
Sand	2.5 x 112=280 „	plus weight of free moisture (.02 x 280=5.6)=286 lbs.
Gravel	3.7 x 112=415 „	plus weight of free moisture (.01 x 415=4.15)=419 lbs.

The field mix by weight is therefore—

$$\frac{112}{112} : \frac{286}{112} : \frac{419}{112} \text{ i.e. } 1 : 2.55 : 3.74$$

2.3.4.6 Quantity of mixing water.

Water 0.62 x 112=69.5—free moisture in sand and coarse aggregate (9.75)

=59.25 lbs.
=say 6 gallons

2.3.4.7 Field Mix by Volume.

The quantities of materials required by volume are:

Cement	=1 bag
Sand $\frac{280}{100}$ x 1.143	=3.2 cft.
Gravel $\frac{419}{90}$ x 1.0256	=4.75 cft.

The field mix by volume is therefore 1 bag : 3.2 cft. : 4.75 cft.

2.3.4.8 Remarks.

A slight variation in the mix from the results of the first example may be noted. This is due to the fact that the percentage of sand to gravel by the method of trial and error has been taken as 40 whereas in the first Example, the Fineness Modulus method gave a percentage of 42.

2.3.5 THE METHOD OF TRIAL MIXES.
(Portland Cement Association, U.S.A.)

In this method also laboratory data on trial concrete mixes made with varying sizes and proportions of aggregates and water content are made use of, in arriving at the proper type of mix for a particular job. Various steps followed in this method are:—

(a) Selection of w/c ratio to get the strength and durability desired.

(b) Selection of slump for desired workability and maximum size of aggregates to be used.

(c) Selection of approximate trial mix for the particular type of aggregates to be used on the job. The total water content and sand to coarse aggregate ratio of this trial mix is used and the exact trial mix for the given aggregates is calculated. If the aggregates as supplied in the field are wet, correction for moisture is made.

(a) W/C RATIOS FOR VARIOUS TYPES OF CONSTRUCTION OR EXPOSURE CONDITIONS

Type or Location of Structure	Severe or Moderate Climate Wide Range of Temperature Hail & Long Freezing Spells					Mild Climate				
	Thin Section		Moderate Section		Heavy Section Mass Concrete	Thin Section		Moderate Section		Heavy Section Mass Concrete
	R.C.C.	Plain	R.C.C.	Plain		R.C.C.	Plain	R.C.C.	Plain	
At the Water Line in Hydraulic Structures Subject to Intermittent Saturation										
In Sea Water	.44	.49	.49	.53	.53	.44	.49	.49	.53	.53
In Fresh Water	.49	.53	.53	.58	.58	.49	.53	.53	.58	.58
Hydraulic Structures away from Water Line but subject to frequent wetting										
By Sea Water	.49	.53	.53	.53	.53	.49	.58	.58	.62	.62
By Fresh Water	.53	.58	.58	.58	.58	.53	.62	.62	.67	.67
Ordinary exposed Structures, Buildings, etc.	.53	.58	.58	.62	.62	.53	.62	.62	.67	.67
Submerged Structures.										
In Sea Water	.53	.58	.58	.62	.62	.53	.58	.58	.62	.62
In Fresh Water	.58	.62	.62	.67	.67	.58	.62	.62	.67	.67
Pavement Slabs										
Wearing Slabs	.49	.53				.53	.58			
Base Slabs	.58	.62				.62	.67			

Curves for selecting w/c ratio for particular strength.
(Portland Cement Association's figures.)

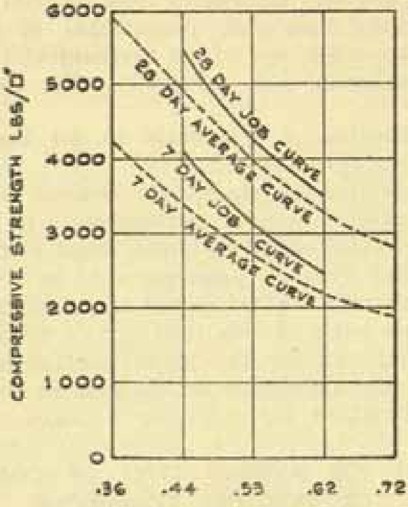


Fig. 2-4.

Results of experiments by Indian Railways for compressive strength of Indian cements (Standard Cylinders).

W/c Ratio By wt.	.33	.45	.55	.66	.78	.89
Min. Compressive Strength @ 7 days lbs./□"	2900	2420	1980	1580	1200	920
Average Comp. Strength @ 7 days lbs./□"	3500	3000	2550	2150	1780	1500
Average Comp. Strength @ 28 days taken as 150% Strength @ 7 days	5250	4500	3825	3225	2670	2250

It will be noted that there is slight difference in the figure in the above two as well as those in table in paragraph 2.3.3. Hence the w/c ratio should be selected by judgment for small jobs and for important big jobs actual tests should be made and curves plotted accordingly.

(b) *Slump for particular job*:—To be selected according to nature of work. Maximum size of aggregates to be used will depend on nature of work and should be as per following table:—

Minimum dimension of section in inches	Max. Size of aggregate in inches			
	R.C. walls beams & cols.	Unreinforced walls	Heavily reinforced Slabs.	Lightly reinforced Slabs.
$2\frac{1}{2}$ to 5	$\frac{1}{2}$ to $\frac{3}{4}$	$\frac{3}{4}$	$\frac{3}{4}$ to 1	$\frac{3}{4}$ to $1\frac{1}{2}$
6 to 11	$\frac{3}{4}$ to $1\frac{1}{2}$	$1\frac{1}{2}$	$1\frac{1}{2}$	$1\frac{1}{2}$ to 3
12 to 29	$1\frac{1}{2}$ to 3	3	$1\frac{1}{2}$ to 3	3
30 or more	$1\frac{1}{2}$ to 3	6	3	3 to 6

(c) *Typical Trial Mixes.*—These are given for medium consistency concrete made with coarse, medium and fine sand and rounded or angular coarse aggregate varying from $\frac{3}{4}''$ maximum size to 2″ maximum size. In calculating the quantities of materials it is necessary to use the principle of absolute volume. It is assumed that in, say, 1 cubic yard of compact concrete water occupies all the voids in cement powder. The cement-water paste occupies all the voids in the sand and cement paste and sand mortar in their turn occupy all the voids in the coarse aggregate. Thus the volume of concrete produced by any combination of materials equals the sum of absolute volume of cement and aggregates and the volume of water. The absolute volume of a loose material is the actual total volume of solid matter in all the loose particles and is obtained as follows:—

$$\text{Absolute volume} = \frac{\text{Wt. of loose material}}{\text{Sp. gravity} \times \text{unit wt. of water}}$$

Specific gravities of materials used in concrete are:—

Cement 3.15; Sand 2.65; Gravel 2.65; Trap 2.90; Granite 2.70; Hard Stone 2.55; Lime Stone 2.65; and Water 1.0.

SUGGESTED TRIAL MIXES FOR CONCRETE OF MEDIUM CONSISTENCY.

(Slump=3")

FINE SAND. (F.M. 2.2 to 2.6) *Rounded Coarse Aggregates.*

Max. Size of C.A.	Water Gals/ Cwt of Cement.	Sand %age of Total	Per Cwt. of Cement		Per Cubic Yard of Concrete				Yield Cubic ft. per Cwt of Cement.
			Sand Lbs.	Gravel Lbs.	Water Lbs.	Cement. Cwts.	Sand Lbs.	Gravel Lbs.	
¾	5	41	200	290	310	6.2	1260	1800	4.35
1	5	36	185	325	300	6.1	1115	1980	4.45
1½	5	32	178	380	280	5.7	1020	2180	4.72
2	5	29	178	430	270	5.4	960	2300	5.05
¾	5½	42	230	320	310	5.6	1310	1810	4.8
1	5½	37	215	362	300	5.4	1170	1985	4.95
1½	5½	33	203	415	280	5.2	1055	2170	5.20
2	5½	30	203	475	270	4.85	985	2320	5.60
¾	6	43	263	345	310	5.2	1360	1800	5.20
1	6	38	245	394	300	5.0	1230	1980	5.35
1½	6	34	232	451	280	4.8	1110	2165	5.65
2	6	31	232	520	270	4.45	1035	2300	6.10
¾	6½	44	292	375	310	4.8	1400	1795	5.65
1	6½	39	275	430	300	4.65	1265	1980	5.85
1½	6½	35	267	495	280	4.38	1170	2160	6.19
2	6½	32	262	560	270	4.10	1080	2300	6.60
¾	7	45	327	400	310	4.45	1460	1775	6.1
1	7	40	304	460	300	4.30	1300	1965	6.3
1½	7	36	292	520	280	4.1	1200	2130	6.5
2	7	33	292	590	270	3.85	1125	2275	7.0
¾	7½	46	361	430	310	4.1	1495	1765	6.6
1	7½	41	332	482	300	4.0	1345	1945	6.7
1½	7½	37	328	560	280	3.8	1240	2115	7.2
2	7½	34	322	625	270	3.6	1160	2260	7.5
¾	8	47	400	334	310	3.85	1540	1750	7.0
1	8	42	370	512	300	3.8	1395	1935	7.2
1½	8	38	357	585	280	3.6	1290	2105	7.5
2	8	38	357	670	270	3.85	1200	2240	8.1

1765

ii FINE SAND (F.M. 2.2 to 2.6) *Angular Coarse Aggregates.*

Max. Size of C.A.	Water Gals/ Cwt of Cement.	Sand %age of Total	Per Cwt. of Cement.		Per Cubic Yard of Concrete				Yield c.ft. per Cwt. of Cement.
			Sand	Stone	Water	Cement.	Sand	Stone	
			Lbs.	Lbs.	Lbs.	Cwts.	Lbs.	Lbs.	
¾	5	46	202	238	335	6.73	1360	1600	4.02
1	5	41	185	268	325	6.55	1210	1755	4.12
1½	5	37	185	310	305	6.22	1150	1925	4.35
2	5	34	185	352	295	5.98	1085	2065	4.60
¾	5½	47	232	262	335	6.13	1420	1605	4.40
1	5½	42	214	298	325	5.96	1280	1775	4.52
1½	5½	38	208	345	309	5.62	1170	1945	4.80
2	5½	35	208	387	295	5.37	1120	2080	5.02
¾	6	48	262	280	335	5.62	1475	1575	4.8
1	6	43	244	321	325	5.46	1330	1755	4.95
1½	6	39	238	369	309	5.20	1240	1920	5.20
2	6	36	238	424	295	4.87	1160	2060	5.55
¾	6½	49	298	304	335	5.2	1520	1580	5.20
1	6½	44	274	345	325	5.04	1380	1740	5.35
1½	6½	40	268	400	309	4.78	1280	1910	5.65
2	6½	37	268	452	295	4.53	1215	2050	5.95
¾	7	50	327	327	335	4.78	1570	1570	5.65
1	7	45	304	369	325	4.70	1430	1735	5.75
1½	7	41	298	428	309	4.45	1325	1910	6.05
2	7	38	298	476	295	4.20	1250	2050	6.42
¾	7½	51	363	345	335	4.45	1615	1540	6.05
1	7½	46	333	393	325	4.36	1460	1715	6.15
1½	7½	42	333	458	309	4.12	1370	1890	6.60
2	7½	39	327	512	295	3.95	1290	2020	6.85
¾	8	52	393	363	335	4.20	1650	1525	6.42
1	8	47	369	417	325	4.12	1520	1715	6.60
1½	8	43	363	482	309	3.86	1405	1865	7.00
2	8	40	363	542	295	3.69	1340	2000	7.32

iii MEDIUM SAND (F.M. 2.6 to 2.9) *Rounded Coarse Aggregates.*

Max. Size of C.A.	Water Gals/ Cwt of Cement.	Sand %age of Total	Per Cwt. of Cement. Sand Lbs.	Per Cwt. of Cement. Gravel Lbs.	Per Cubic Yard of Concrete. Water Lbs.	Per Cubic Yard of Concrete. Cement. Cwts.	Per Cubic Yard of Concrete. Sand Lbs.	Per Cubic Yard of Concrete. Gravel Lbs.	Yield C. ft. per Cwt of Cement.
¾	5	43	214	280	310	6.2	1330	1740	4.35
1	5	38	196	321	300	6.1	1190	1945	4.45
1½	5	34	190	369	280	5.7	1090	2110	4.72
2	5	31	190	417	270	5.4	1025	2240	5,05
¾	5½	44	244	310	310	5.6	1370	1740	4.80
1	5½	39	226	357	300	5.4	1235	1950	4.95
1½	5½	35	214	405	280	5.2	1115	2115	5.20
2	5½	32	214	464	270	4.9	1045	2260	5.60
¾	6	45	274	333	310	5.2	1425	1735	5.20
1	6	40	256	381	300	5.0	1290	1920	5.35
1½	6	36	244	434	280	4.8	1170	2080	5.65
2	6	33	250	506	270	4.45	1110	2250	6.10
¾	6½	46	310	363	310	4.8	1480	1740	5.65
1	6½	41	292	417	300	4.65	1320	1925	5.85
1½	6½	37	280	476	280	4.38	1220	2080	6.19
2	6½	34	280	542	270	4.10	1150	2230	6.60
¾	7	47	339	387	310	4.45	1510	1725	6.1
1	7	42	321	440	300	4.30	1375	1890	6.3
1½	7	38	310	500	280	4.10	1275	2060	6.5
2	7	35	310	572	270	3.85	1195	2210	7.0
¾	7½	48	381	417	310	4.1	1570	1715	6.6
1	7½	43	352	464	300	4.0	1415	1875	6.7
1½	7½	39	345	542	280	3.75	1305	2050	7.2
2	7½	36	339	607	270	3.6	1225	2190	7.5
¾	8	49	418	434	310	3.85	1610	1680	7.0
1	8	44	387	494	300	3.8	1465	1870	7.2
1½	8	40	374	560	280	3.6	1355	2020	7.5
2	8	37	381	643	270	3.85	1280	2160	8.1

iv. Medium Sand (F.M. 2.6 to 2.9) *Angular Coarse Aggregates.*

Max. Size of C.A.	Water Gals/ Cwt of Cement.	Sand %age of Total	Per Cwt. of Cement.		Per Cubic Yard of Concrete.				Yield C. ft. per Cwt of Cement.
			Sand	Stone	Water	Cement.	Sand	Stone	
			Lbs.	Lbs.	Lbs.	Cwts.	Lbs.	Lbs.	
¾	5	48	208	226	335	6.73	1400	1520	4.02
1	5	43	196	262	325	6.55	1290	1715	4.12
1½	5	39	190	298	305	6.22	1185	1850	4.35
2	5	36	190	345	295	5.98	1120	2030	4.60
¾	5½	49	238	250	335	6.13	1460	1535	4.40
1	5½	44	226	286	325	5.96	1350	1705	4.52
1½	5½	40	333	333	305	5.62	1240	1875	4.80
2	5½	37	375	375	295	5.37	1185	2015	5.02
¾	6	50	274	274	335	5.62	1540	1540	4.8
1	6	45	256	310	325	5.46	1400	1690	4.95
1½	6	41	250	357	305	5.20	1300	1860	5.20
2	6	38	250	411	295	4.87	1220	2000	5.55
¾	6½	51	304	292	335	5.20	1580	1520	5.20
1	6½	46	286	333	325	5.04	1440	1680	5.35
1½	6½	42	280	387	305	4.78	1340	1850	5.65
2	6½	39	280	440	295	4.53	1270	2000	5.95
¾	7	52	339	316	335	4.78	1625	1510	5.65
1	7	47	316	357	325	4.70	1480	1680	5.75
1½	7	43	310	417	305	4.45	1380	1855	6.05
2	7	40	316	470	295	4.20	1325	1975	6.42
¾	7½	53	375	333	335	4.45	1670	1485	6.05
1	7½	48	352	381	325	4.36	1535	1665	6.15
1½	7½	44	352	440	305	4.12	1445	1810	6.60
2	7½	41	345	494	295	3.95	1360	1950	6.85
¾	8	54	411	345	335	4.20	1725	1540	6.42
1	8	49	381	400	325	4.12	1570	1640	6.60
1½	8	45	381	470	305	3.88	1470	1820	7.00
2	8	42	381	524	295	3.69	1410	1935	7.32

v COARSE SAND (F.M. 2.9 to 3.2) *Rounded Coarse Aggregates.*

Max. Size of C.A.	Water Gals/ Cwt of Cement.	Sand %age of Total	Per Cwt of Cement		Per Cubic Yard of Concrete				Yield C. ft. per Cwt of Cement.
			Sand	Stone	Water	Cement.	Sand	Stone	
			Lbs.	Lbs.	Lbs.	Cwts.	Lbs.	Lbs.	
¾	5	45	220	274	310	6.4	1370	1700	4.35
1	5	40	208	310	300	6.1	1260	1870	4.45
1½	5	36	202	357	280	5.7	1155	2040	4.72
2	5	33	202	405	270	5.4	1090	2175	5.05
¾	5½	46	256	298	310	5.6	1440	1675	4.80
1	5½	41	238	339	300	5.4	1300	1855	4.95
1½	5½	37	226	393	280	5.2	1180	2045	5.20
2	5½	34	232	446	270	4.9	1130	2175	5.60
¾	6	47	286	321	310	5.2	1490	1675	5.20
1	6	42	268	369	300	5.0	1350	1860	5.35
1½	6	38	262	424	280	4.8	1250	2020	5.65
2	6	35	262	488	270	4.45	1165	2170	6.10
¾	6½	48	321	345	310	4.8	1540	1650	5.65
1	6½	43	304	400	300	4.65	1400	1840	5.85
1½	6½	39	298	464	280	4.38	1300	2030	6.1[illegible]
2	6½	36	298	524	270	4.10	1225	2160	6.60
¾	7	49	357	369	310	4.45	1590	1640	6.1
1	7	44	333	428	300	4.30	1430	1835	6.3
1½	7	40	321	482	280	3.10	1320	1985	6.5
2	7	37	321	554	270	3.85	1240	2140	7.0
¾	7½	50	400	400	310	4.1	1640	1640	0.6
1	7½	45	369	446	300	4.0	1490	1800	6.7
1½	7½	41	363	524	280	3.75	1375	1980	7.2
2	7½	38	357	590	270	3.60	1290	2130	7.5
¾	8	51	435	417	310	3.85	1680	1610	7.0
1	8	46	405	476	300	3.80	1530	1800	7.2
1½	8	42	393	542	280	3.60	1420	1960	7.5
2	8	39	400	625	270	3.85	1340	2100	8.1

vi COARSE SAND (F.M. 2.9 to 3.2) *Angular Coarse Aggregates.*

Max. Size of C.A.	Water Gals/ Cwt of Cement.	Sand %age of Total	Per Cwt. of Cement.		Per Cubic Yard of Concrete.				Yield C. ft. per Cwt of Cement.
			Sand Lbs.	Stone Lbs.	Water Lbs.	Cement. Cwts.	Sand Lbs.	Stone Lbs.	
¾	5	50	220	220	335	6.73	1480	1480	4.02
1	5	45	202	250	325	6.55	1325	1640	4.12
1½	5	41	203	290	305	6.22	1260	1810	4.35
2	5	38	199	328	295	5.98	1190	1960	4.60
¾	5½	51	250	238	335	6.13	1535	1460	4.40
1	5½	46	232	275	325	5.96	1385	1635	4.52
1½	5½	42	232	322	305	5.62	1310	1810	4.80
2	5½	39	232	364	295	5.37	1250	1950	5.02
¾	6	52	280	262	335	5.62	1575	1475	4.8
1	6	47	268	296	325	5.46	1460	1625	4.95
1½	6	43	262	346	305	5.20	1360	1800	5.20
2	6	40	263	398	295	4.87	1280	1940	5.55
¾	6½	53	316	280	335	5.20	1640	1460	5.20
1	6½	48	290	322	325	5.04	1500	1620	5.35
1½	6½	44	294	368	305	4.78	1400	1795	5.65
2	6½	41	298	430	295	4.53	1350	1920	5.95
¾	7	54	350	296	335	4.78	1680	1425	5.65
1	7	49	328	346	325	4.70	1540	1625	5.75
1½	7	45	327	398	305	4.45	1455	1775	6.05
2	7	42	330	452	295	4.20	1400	1900	6.42
¾	7½	55	394	322	335	4.45	1750	1430	6.05
1	7½	50	229	229	325	4.36	1585	1585	6.15
1½	7½	46	366	430	305	4.12	1520	1765	6.60
2	7½	43	362	475	295	3.95	1430	1880	6.85
¾	8	56	423	384	335	4.20	1775	1400	6.42
1	8	51	398	380	325	4.12	1640	1570	6.60
1½	8	47	400	452	305	3.86	1540	1750	7.00
2	8	44	400	506	295	3.69	1475	1870	7.32

Note.—The preceding tables apply to concrete of 3 inches slump and made with natural sand. For concrete with different slump and made with stone sand the following adjustment should be made before using the tables:—

(1) Increase or decrease water content by 3% for each increase or decrease of 1 inch in slump.

(2) For stone sand increase percentage of sand by about 3 and water content by about 15 lbs. per cubic yard of concrete. For less workable concrete as in pavements decrease percentage of sand by about 3 and water content by 8 lbs. per cubic yard of concrete.

An illustrative example will make the procedure clear. A reinforced concrete structure of thin section is to be exposed to fresh water in a severe climate where freezing and thawing takes place. The strength of concrete required is 3,750 lbs./sq. in. The C. Aggregate to be used is gravel 1½" downwards carrying free moisture of 1%. The fine aggregate consists of natural sand of f.m. 2.5 with free moisture of 3%. The specific gravities of both are 2.65. The slump required for the concrete is 4".

W/c ratio from table on page 47=.49, i.e., say 5½ gals.|cwt.
Do. graph on page 48=.55
Take the lower figure of .49.

Approximate trial mix from page 50 is

1 cwt. of cement: 203 lbs. of sand: 415 lbs. of gravel.

The percentage of sand will be about 33 and 280 lbs. of water will be required per cubic yard of concrete.

From these assumptions we shall find out the correct trial mix for 4" slump since the table gives figures for 3" slump.

Water required for 4" slump $= 1.03 \times 28.0 = 29.0$ gallons

Cement required per cubic yard of concrete

$$\frac{29.0}{5.5} = 5.3 \text{ cwts say } 5.4 \text{ bags}$$

% age of sand given in the table is 33

absolute volume of Cement $= \dfrac{5.4 \times 110}{3.15 \times 62.3} = 3.07$ cft.

volume of water required $= \dfrac{29.0}{6.25} = 4.70$ cft.

∴ volume of Cement paste $= 7.77$ cft

∴ absolute volume of aggregates $= 27 - 7.77 = 19.23$ cft.

∴ absolute volume of sand $= .33 \times 19.23 = 6.35$ cft.

∴ wt. of surface dry sand $= 6.35 \times 2.65 \times 62.3$
$= 1048$ lbs.

& absolute volume of gravel $= .67 \times 19.23 = 12.90$ cft.

∴ weight of surface dry gravel $= 12.90 \times 2.65 \times 62.3$
$= 2130$ lbs.

and so for each bag of cement (110 lbs.)

we require, $\dfrac{1048}{5.4} = 195$ lbs. of sand and

$$\frac{2130}{5.4} = 394 \text{ lbs. of gravel}$$

Since the sand and gravel are wet we must take

$$195+\frac{3}{100}\times 195 = 195+6=201 \text{ lbs. of wet sand}$$

and $394+\dfrac{1}{100}\times 394 = 394+4=398$ lbs. of wet gravel

The water to be added to the mix will be $5.5 - \dfrac{6+4}{10}$ gallons

$= 4.5$ gallons.

corrected field mix for trial is

1 bag of cement (110 lbs. net)
201 lbs. of sand
398 lbs. of gravel and
4.50 gallons of water.

CHAPTER 3

LOADS, BENDING MOMENTS AND SHEARING FORCES

CONTENTS

CHAPTER 3

LOADS, BENDING MOMENTS AND SHEARING FORCES

3.1 DEAD LOADS.

(i) Weights of Materials :

(a) Bituminous substances :

	lbs./c.ft.
Asphaltum	81
Coal anthracite	97
„ bituminous	84
„ lignite	78
„ peat	47
„ charcoal light	23
„ „ heavy	33
„ coke	75
Graphite	31
Paraffin	56
Petroleum (crude)	55
„ (refined)	50
Pitch	69
Tar bituminous	75

(b) Excavated Materials :

	lbs./c.ft.
Clay dry	63
„ damp plastic	110
Clay & gravel dry	110
Earth dry loose	76
„ „ packed	95
„ moist loose	78
„ „ packed	96
„ mud flowing	108
„ „ packed	115
Riprap	80 to 90
Sand gravel dry loose ..	90 to 105
„ packed ..	100 to 120
„ wet ..	118 to 120

(c) Liquids:

	lbs./c.ft.
Alcohol	49
Acids muriatic	75
„ nitric	94
„ sulphuric	112
Oils vegetable	58
„ mineral	57
Petroleum	55
Gasoline	42
Water fresh	62.4
„ sea	64.0
Ice	57

(d) Minerals & Building Stones:

Asbestos	153
Barytes	281
Basalt	184
Bauxite	159
Chalk	137
Clay marl	137
Copper ore (pyrites) ..	262
Dolomite	181
Granite	175
Hematite	325
Gypsum	159
Hornblende	187
Limestone marble	165
Lead ore (galena)	465
Magnesite	187
Porphyry	172
Pumice	40
Quartz	165
Sandstone	175
Soapstone	169
Lime (ore)	253
Cement	90

(e) Metals:

Aluminium	165
Brass	534
Bronze	509
Chromium	428
Copper	556
Gold	1205

	lbs./c.ft.
Iron (pig)	450
„ (wrought)	485
„ (steel)	490
Lead	706
Magnesium	109
Manganese	456
Mercury	848
Nickel	545
Platinum	1330
Silver	656
Tin	459
Tungsten	1180

(f) Timber:

Anjan (Ternimatia Tomentosa)	53–60
Anjan (Hardwickia Binata)	82
Babul (Acacia arabica) ..	54
Bambu	71
Cocoanut	57—70
Cedar (white)	22
Deal (yellow)	27
Fir	25—30
Hirda	32
Jambul	47
Kalamb (styphegyne paroifolia)	42
Khair (acacia catechu) ..	66
Mango	42
Oak (white)	46
Pine (red)	30
Sissue (Tali)	50
Tamarind	79
Teak	41–45
Walnut	38

(g) Solids (miscellaneous):

Bricks	100
Bakelite	80—120
Carbon	129
Cork	15
Ebony	76
Glass (common)	160
Paper	60
Phosphorus	114
Porcelain	150

	lbs./c.ft.
Resin	67
Rubber	58
Silicon	155
Sulphur	128
Wax	60

(h) Stored Material:

Animal food	64
Alum	106
Beans (canned)	43
Boiled oil	59
Books (on shelves)	40
" Bulk	60
Butter	59
Camphor	62
Candles	32
Celluloid	84–100
" goods	10
Chains	160
Chocolate	34
Cigarettes (cases)	15
Cloth	30
Cloves bales	20
Cocoanut oil	58
Coffee bags	28–32
" beans	40
Cotton raw compressed ..	25–36
" pressed	17
" piece goods	25–30
" seed bags	43
Cutlery cases	37
Drugs cases	26
Dyes	28
Eggs (crates)	22
Fancy goods mixed	12
Files (cases)	56
Flour sacks	40
Fruit (dry)	60

	lbs/c.ft.
Glycerine (drums) ..	50
Grain barley	39
oats	26
rye	45
maize .. .	47
rice bags ..	50
wheat	49
Ground nuts (bags)	39
Honey	90
Hosiery (cased)	14
Ice	57
Jaggery	56
Jute bales	30
Linen goods	35
Machinery cases	28
Manila ropes	32
Milk	64
„ cases	38
„ powder	23
Oilcake bags	41
Paint aluminium	70
bituminous	70
red lead	195
zinc	150
Perfumery (cases)	28
Rags (baled)	13
Rubber cases	25
„ raw	50
Salt bulk	60
„ bags	45
Soap (boxed)	57
Soft drinks cases	27
Starch	59
Sugar bags ..	45–50
Tea chests	22
Tobacco packets	18
Wine bulk	61
Wine bottles in cases ..	37

(ii) Structural items, ceiling, finishes, etc.

Asbestos cement flat sheets ¼″ thick 2¼ lbs./s.ft.

		lbs./c.ft.
Concrete reinforced		144 to 150
with 1% steel	..	148
2% „	..	151
5% „	..	161
Concrete: plain	.. ..	140
„ with brick aggregate		120
„ breeze	.. ..	70 to 90
„ lime	.. ..	120
„ pumice	.. ..	50 to 55
„ sawdust	.. ..	70
„ aerated or cell	..	16
Flooring: cork	1″ thick	2
fibre board	„	1½
granolithic	„	12
hardwood	⅞″ in mastic	4
macadam tar	1″ thick	11
terrazzo	„	12
		lbs./c.ft.
Masonry: ashlar	.. ..	165
rubble	.. ..	150
dry rubble	..	130
brick	.. ..	120
		lbs./s.ft
Partitions: 9″ brickwork	..	90
3″ breeze	..	24
2″ hollow block		9
3″ „	..	12½
4″ „	..	15
G. I. sheets	..	3
lath & plaster		8
clay tile partitions		
3″ thick		18

		lbs./s ft.
Plasters: lime	1″ thick	9
cement	„	11
gypsum	„	7
Roofing: asbestos sheet $\frac{1}{4}$″ thick	..	$3\frac{1}{2}$
asbestos sheet roofing complete		10
bituminous felt	..	$1\frac{1}{2}$
boarding soft wood $\frac{3}{4}$″ thick	..	2
G.I. sheets 24 G	..	1
„ „ 18 G	..	2
G.I. sheet roofing complete with purlins etc.	..	4
Ruberoid 5 layers.		$1\frac{3}{4}$
Shingles	..	$1\frac{1}{2}$
Slates 1·5″ thick		7
Tiling clay	..	$8\frac{1}{2}$
„ Mangalore with battens		14
„ single country with battens		14
„ double country with battens		24
Thatching 9″ including frame		10
„ 6″ including frame		$6\frac{1}{2}$

3.2 LIVE LOADS.

(a) London Building Bye-Laws.

No.	Description.	Loading in Lbs./s.ft. of floor area	
		Slabs	Beams
1.	Residential Rooms, Corridors, Stairs Landings within curtilage of Residence	50 or $\frac{560}{S}$ whichever	40 or $\frac{2240}{S}$ is more
2.	Office floors above entrance floor	80 or $\frac{840}{S}$	50 or $\frac{4480}{S}$
3.	Office floor, entrance floor & below entrance floor	80 or $\frac{840}{S}$	80 or $\frac{4480}{S}$
	Retail Shops, Garages for Cars $2\frac{1}{2}$ Ton wt. Maximum	Add 20 lbs./s.ft. for partitions in case of offices.	
4.	Corridors, stairs & landings except those in Class I	100 or $\frac{840}{S}$	100 or $\frac{4480}{S}$
5.	(a) Workshop & Factories	150 or $\frac{840}{S}$	120 or $\frac{4480}{S}$
	(b) Garages for Cars over $2\frac{1}{2}$ Tons.	150 or 1.5 Max. Combined wheel load	120 or 1.5 Max. wheel load combined.
6.	Ware Houses, Book stores, Stationery Stores	200 or $\frac{840}{S}$	200 or $\frac{4480}{S}$
	ADDITIONAL FLOORS SPECIFIED BY D.S.I.R. CODE OF PRACTICE.		
1.	Hotel Bed Rooms, Hospital Rooms & Wards	As (1)	Above
2.	Churches, Schools, Reading Rooms, Art Galleries	As (3)	Above
3.	Assembly Halls, Drill Halls, Dance Halls, Gymnasiums, Public Spaces in Hotels & Hospitals, Theatres, Cinemas, Restaurants Grand Stalls.	As (4)	Above
1.	Roofs Inclination $<$ 20° to Horizontal	50	30
	Do. .. $>$ .. (Loads to be taken on Plan Area)	15 lbs./s.ft. Normal to surface acting inwards on windward side. 10 lbs./s.ft. normal to surface and acting outwards on leeward side	

Note.—In Case of Nos. 5 & 6 above use actual loading if more than specified above.
S denotes span in feet.

(b) B.S. Code..

No.	Description.	Normal Load lbs/s.ft.	Min. Total Load lbs. Slabs	Beams
1.	Dwelling > 2 Storeys	30	240	1920
	Do < 2 „ Flats, Hotel Bed Rooms, Hospital Rooms & Wards.	40	320	2560
	Public Rooms in Hotels	100	800	6400
2.	Office Rooms	50	400	3200
	Bank Halls Public Offices ..	70	560	4480
	Filing & Record Rooms ..	100	800	6400
	Light Storage Space	150		
	General storage space, Ware Houses	200		
	Retail Shops	80		
3.	Light Workshops (Min.) ..	60		
	Do. including Machinery	100	800	6400
	Circulation space in machinery halls	80	640	5120
	Medium workshops, Light Storage Space	150		
	Heavy Workshops, General Storage Space	200		
4.	Churches, Chapels, Restaurants (with fixed seating)	80	640	5120
	School & College Class Rooms ..	60	480	3840
	Dance Halls (without fixed seating)	100	800	6400
5.	Roof : Flat < 10° to Horizontal ..	30	240	
	„ Inclined (> 10° ≯ 65° to Horizontal) ..	10		

Notes : *Stairs Landing & Corridors :* Design for same load as floor to which access is given but with max. load=80 lbs./s.ft. (min. load on slabs to be 640 lbs. and for beams=5120 lbs.). Same loads apply to places of assembly with fixed seating.

(c) Typical American Building Code — Live Loads.

		Lbs./s.ft
1.	Residences	40
2.	Places for Assembly or Public Purposes	100
3.	Class Rooms of Schools or other places of Instruction ..	75
4.	Offices.	50
5.	Floors or any other Class not included above ..	120
6.	Roofs Pitch < 20°	40
7.	„ „ > 20°	30
8.	Side Walks between Curb & Building	300
9.	Yards & Courts inside the Building Line	120

(d) Old L.C.C. Regulation (1909) — Live Loads.

		Lbs./sq. ft.
1.	Domestic Buildings	70
2.	Asylum Wards, Lodging House Bed Rooms, Hospital Wards, Hotel Bed Rooms, Work House Wards etc.	84
3.	Counting Houses, Offices etc.	100
4.	Art Galleries, Chapels, Churches, Class Rooms, Lecture Halls, Music Halls, Public Halls, Workshops, Retail Shops, Theatres etc. etc.	112
5.	Ball Rooms, Drill Room, Floors subjected to Vibration	150
6.	Book Stores, Museums, Ware Houses etc.	224

3.3 FORMULAE for B. M. and S.F.

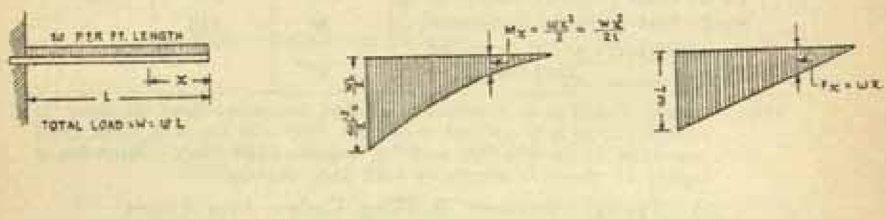
3·3·1 CANTILEVERS

LOAD DIAGRAM — B M DIAGRAM — S F DIAGRAM

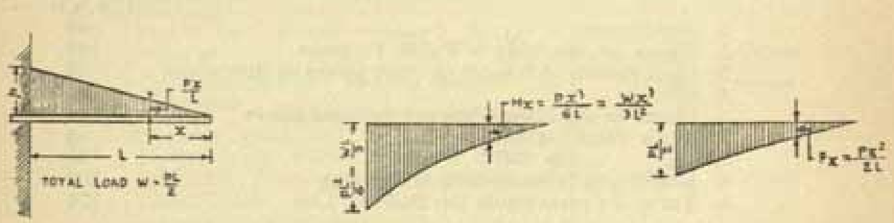
3·3·1.1

3·3·1·2

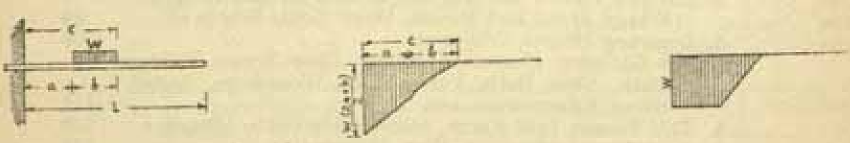
3·3·1·3



3·3·1·4

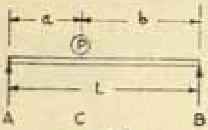


3·3·1·5



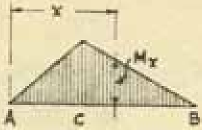
3·3·2 SIMPLY SUPPORTED BEAMS

3·3·2·1



$R_A = \frac{Pb}{L}$

$R_B = \frac{Pa}{L}$

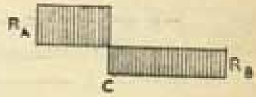


$M_C = \frac{Pab}{L}$

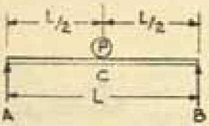
$= R_A a$

$= R_B b$

$M_x = \frac{Px(L-x)}{2L}$

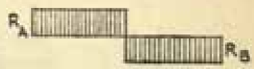


3·3·2·2

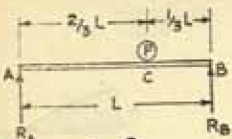


$R_A = R_B = P/2$

$M_C = \frac{PL}{4}$



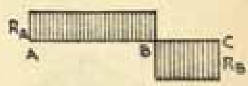
3·3·2·3



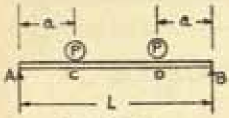
$R_A = P/3$

$R_B = 2/3 P$

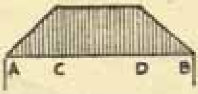
$M_C = \frac{2PL}{9}$



3·3·2·4

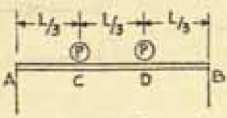


$R_A = R_B = P$



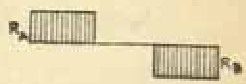
$M_C = M_D = Pa$

3·3·2·5

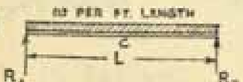


$R_A = R_B = P$

$M_C = M_D = \frac{PL}{3}$

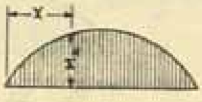


3·3·2·6



$R_A = R_B = \frac{wL}{2} = \frac{W}{2}$

$(W = wL)$

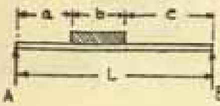


$M_C = \frac{wl^2}{8} = \frac{WL}{8}$

$M_x = \frac{Wx(L-x)}{2L}$

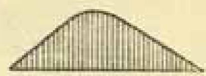
SIMPLY SUPPORTED BEAMS

3.3.2.7



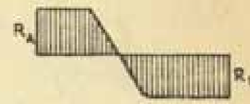
$R_A = \frac{W}{L}\left(\frac{b}{2} + c\right)$

$R_B = \frac{W}{L}\left(\frac{b}{2} + a\right)$

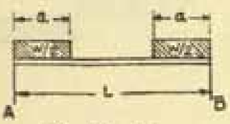


$M_{MAX.} = \frac{W}{b}\left(\frac{y^2 - a^2}{2}\right)$

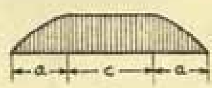
WHERE $y = a + \frac{R_A}{W} b$



3.3.2.8



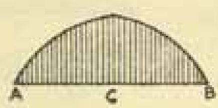
$R_A = W/2 = R_B$



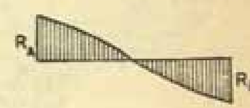
$M_C = \frac{Wa}{4}$

3.3.2.9

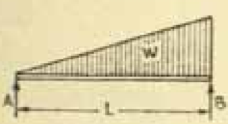
$R_A = R_B = \frac{W}{2}$



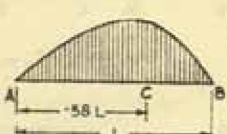
$M_C = \frac{WL}{6}$



3.3.2.10

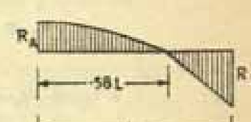


$R_A = \frac{W}{3}$ $\quad R_B = \frac{2W}{3}$



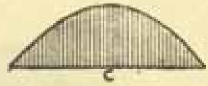
$M_C = \frac{WL}{7.8}$

$M_x = \frac{Wx(L^2 - x^2)}{3L^2}$



3.3.2.11

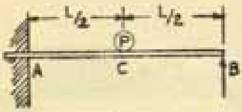
$R_A = \frac{W}{2} = R_B$



$M_C = \frac{WL}{8}$

3·3·3 PROPPED CANTILEVER

3·3·3·1

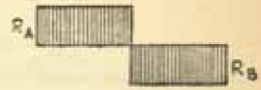


$R_A = \frac{11}{16}P$

$R_B = \frac{5}{16}P$

$M_A = -\frac{3PL}{16}$

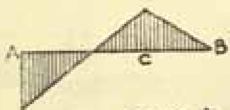
$M_C = +\frac{PL}{6{\cdot}4}$



3·3·3·2

$R_A = \frac{Pb\,(3L^2-b^2)}{2L^3}$

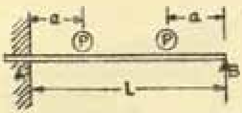
$R_B = \frac{Pa^2\,(2L+b)}{2L^3}$



$M_A = -\frac{Pab\,(L+b)}{2L^2}$

$M_C = +\frac{Pa^2b\,(2a+3b)}{2L^3}$

3·3·3·3

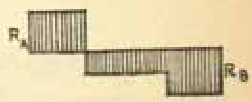


$R_A = \frac{(2L^2+3La-3a^2)P}{2L^2}$

$R_B = \frac{(2L^2-3La+3a^2)P}{2L^2}$

$M_A = -\frac{3Pa\,(L-a)}{2L}$

$M_C = +\frac{Pa\,(2L^2-3La+3a^2)}{2L^2}$



3·3·3·4

$R_A = 5/8\,W$

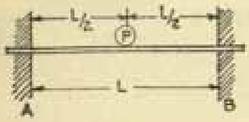
$R_B = 3/8\,W$

$M_A = -\frac{WL}{8}$

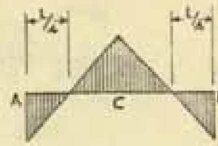
$M_C = +\frac{WL}{14{\cdot}2}$

3·3·4 FIXED ENDED BEAMS

3·3·4·1

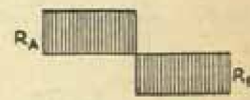


$R_A = R_B = P/2$

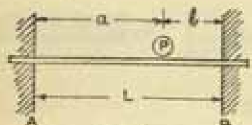


$M_A = M_B = \frac{PL}{8}$

$M_C = \frac{PL}{8}$



3·3·4·2



$a > b$

$R_A = \frac{Pb^2(L+2a)}{L^3}$

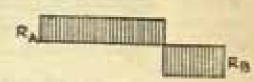
$R_B = \frac{Pa^2(L+2b)}{L^3}$

$M_A = \frac{Pab^2}{L^2}$

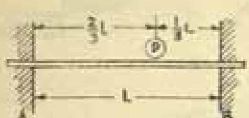
$M_B = \frac{Pa^2b}{L^2}$

$M_C = \frac{2Pa^2b^2}{L^3}$

$M_{MAX} = MB$



3·3·4·3



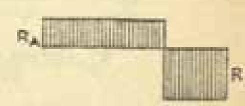
$R_A = \frac{7P}{27}$

$R_B = \frac{20P}{27}$

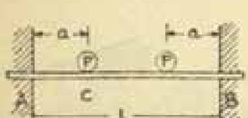
$M_A = \frac{PL}{13·5}$

$M_B = \frac{PL}{6·75}$

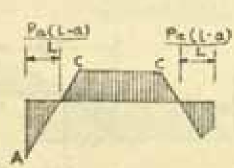
$M_C = \frac{PL}{18·1}$



3·3·4·4

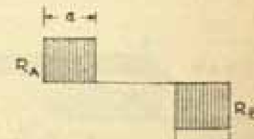


$R_A = R_B = P$



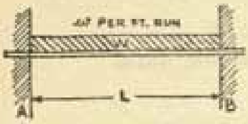
$M_A = M_B = \frac{Pa(L-a)}{L}$

$M_C = \frac{Pa^2}{L}$

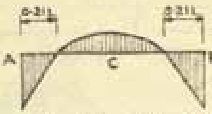


FIXED ENDED BEAMS

3·3·4·5



$R_A = \frac{wL}{2} = \frac{W}{2} = R_B$



$M_A = M_B = -\frac{wL^2}{12} = -\frac{WL}{12}$

$+M_C = \frac{wL^2}{24} = +\frac{WL}{24}$

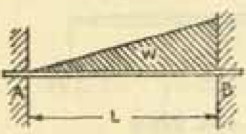
3·3·4·6

$R_A = R_B = \frac{W}{2}$

$M_A = M_B = -\frac{WL}{9·6}$

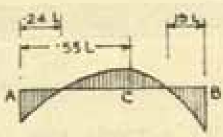
$M_C = +\frac{WL}{16}$

3·3·4·7



$R_A = \frac{3W}{10}$

$R_B = \frac{7W}{10}$



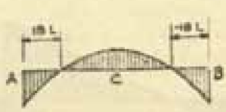
$M_A = -\frac{WL}{15}$

$M_B = \frac{WL}{10}$ (MAX.)

$M_C = \frac{WL}{23}$

3·3·4·8

$R_A = R_B = \frac{W}{2}$

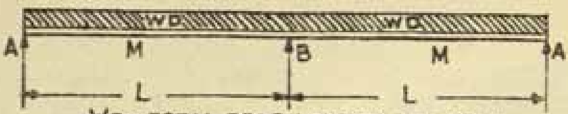


$M_A = M_B = \frac{WL}{16}$

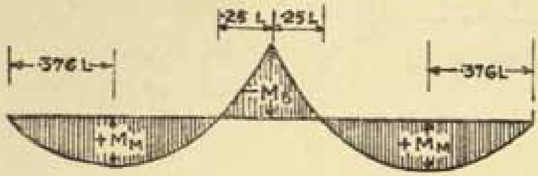
$M_C = +\frac{WL}{48}$

3·3·5 TWO EQUAL SPANS

3·3·5·1

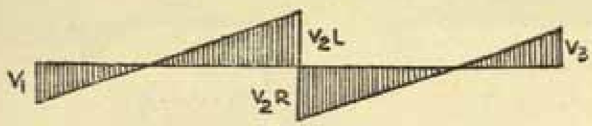


W_D = TOTAL DEAD LOAD ON ONE SPAN



$M_M = +\cdot07\ W_D L$

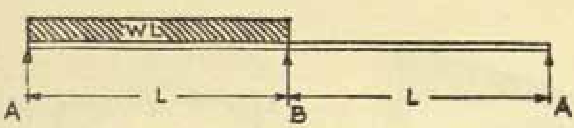
$M_B = -\cdot125\ W_D L$



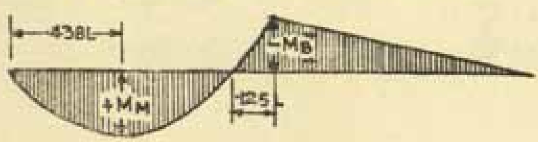
$V_1 = 3/8\ W_D = V_3$

$V_2L = V_2R = 5/8\ W_D$

3·3·5·2

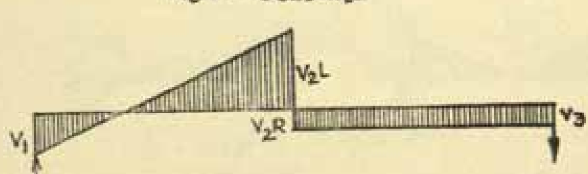


W_L = TOTAL LIVE LOAD ON ONE SPAN



$M_M = +\cdot096\ W_L L$

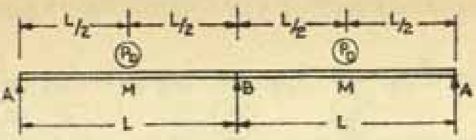
$M_B = -\cdot0625\ W_L L$



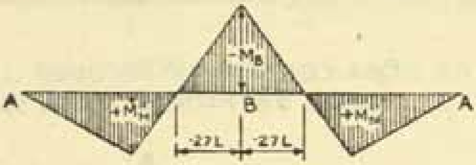
$V_1 = \frac{7}{16}\ W_L$ $\qquad$ $W_2R = \frac{1}{16}\ W_L$

$V_3 = -\frac{1}{16}\ W_L$ $\qquad$ $W_2L = \frac{9}{16}\ W_L$

3·3·5·3



PD = CONCENTRATED DEAD LOAD
ON CENTRE OF EACH SPAN



DEAD LOAD MOMENTS

$M_M = + \cdot 156\ P_D L$

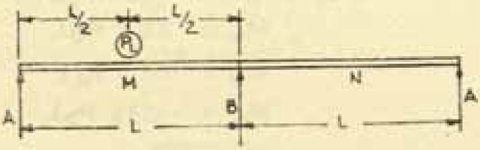
$M_B = - \cdot 188\ P_D L$

DEAD LOAD SHEARS

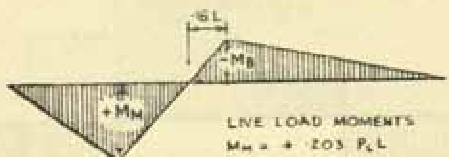
$V_1 = \cdot 312\ P_D = V_3$

$V_2 L = V_2 R = \cdot 688\ P_D$

3·3·5·4



P_L = CONCENTRATED LIVE LOAD
ON CENTRE OF ONE SPAN

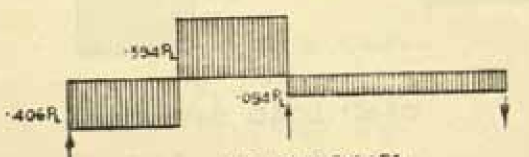


LIVE LOAD MOMENTS

$M_M = + \cdot 203\ P_L L$

$M_B = - \cdot 094\ P_L L$

$M_N = + \cdot 047\ P_L L$



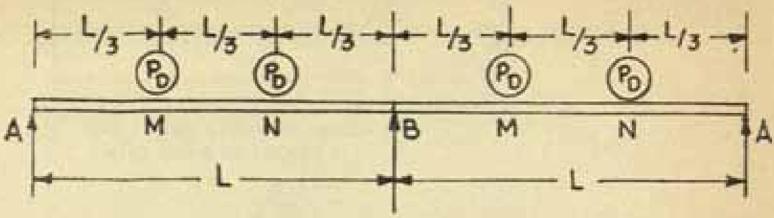
LIVE LOAD SHEARS

$V_1 = \cdot 406\ P_L$

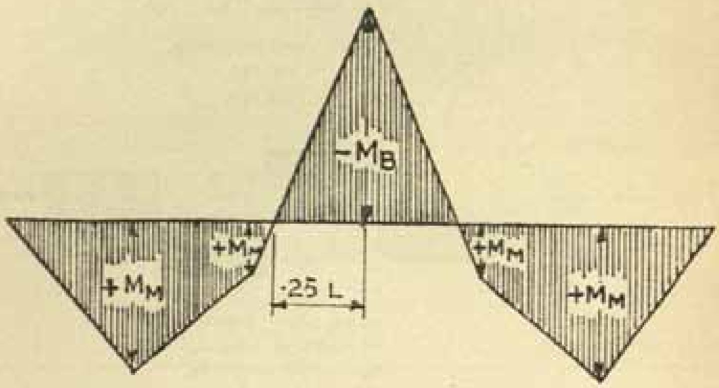
$V_{2L} = \cdot 594\ P_L$ $\qquad V_2 R = \cdot 094\ P_L$

$V_3 = - \cdot 094\ P_L$

3·3·5·5



P_D = CONCENTRATED DEAD LOAD AT 3RD POINT OF EACH SPAN

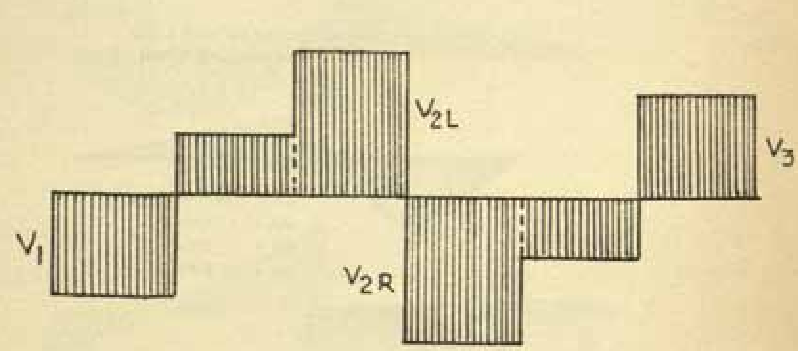


DEAD LOAD MOMENTS

$M_M = \cdot 222\ P_D L$

$M_N = \cdot 111\ P_D L$

$M_B = -\cdot 333\ P_D L$

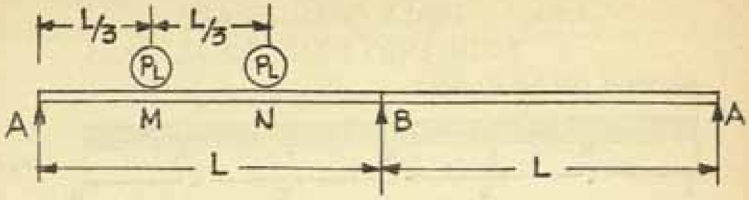


DEAD LOAD SHEARS

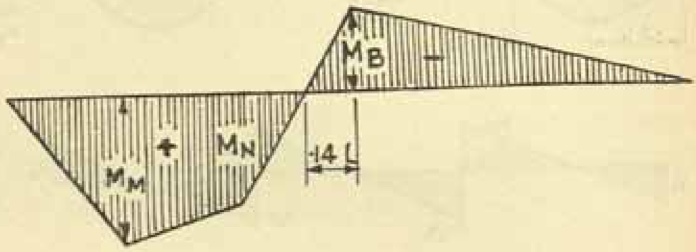
$V_1 = V_3 = \cdot 667\ P_D$

$V_2L = V_2R = 1\cdot 333\ P_D$

3·3·5·6



CONCENTRATED LIVE LOADS AT
3RD POINTS OF ONE SPAN ONLY

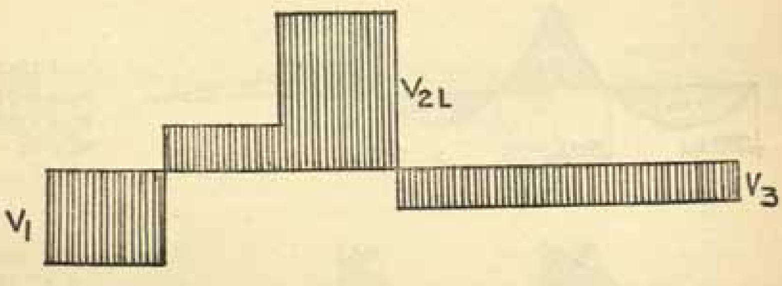


LIVE LOAD MOMENTS

$M_M = \cdot 277\ P_L L$

$M_N = \cdot 222\ P_L L$

$M_B = -\cdot 167\ P_L L$



LIVE LOAD SHEARS

$V_1 = \cdot 833\ P_L$

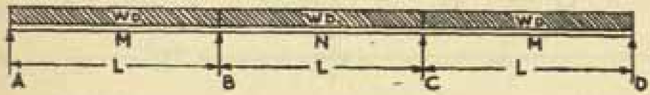
$V_2 L = 1{\cdot}167\ P_L$

$V_3 = -\cdot 167\ P_L$

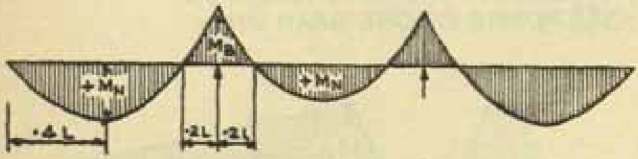
3-3-6 THREE SPAN BEAMS
BOTH ENDS FREE, EQUAL SPANS

ALL SPANS UNIFORMLY LOADED

3-3-6-1



W_D = TOTAL DEAD LOAD ON ONE SPAN

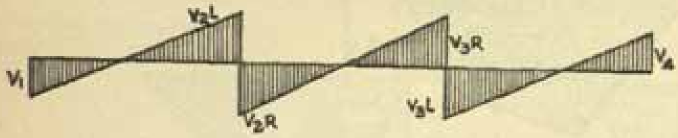


DEAD LOAD MOMENTS

$M_M = +\cdot 08\ W_D L$

$M_N = +\cdot 025\ W_D L$

$M_B = -\ 0\cdot 1\ W_D L$



DEAD LOAD SHEARS

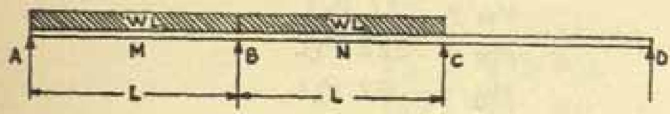
$V_1 = V_4 = \cdot 4\ W_D$

$V_2L = V_3L = \cdot 5\ W_D$

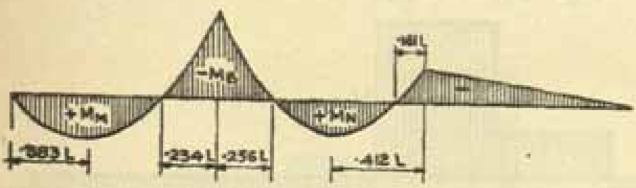
$V_2R = V_3R = \cdot 6\ W_D$

TWO ADJACENT SPANS LOADED

3-3-6-2



W_L = TOTAL LIVE LOAD ON ONE SPAN



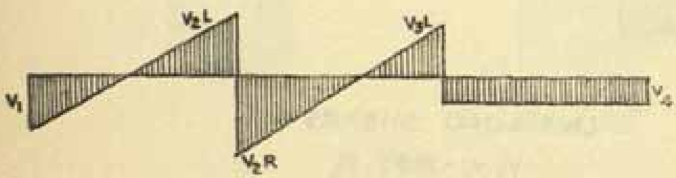
LIVE LOAD MOMENTS

$M_M = +\cdot 0735\ W_L L$

$M_N = +\cdot 0535\ W_L L$

$M_B = -0\cdot 117\ W_L L$

$M_C = -\ \cdot 033\ W_L L$



LIVE LOAD SHEARS

$V_1 = \cdot 383\ W_L$

$V_2R = \cdot 617\ W_L$

$V_2L = \cdot 583\ W_L$

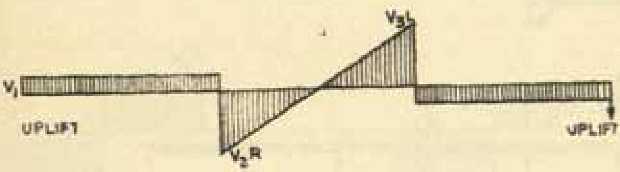
$V_3L = \cdot 417\ W_L$

$V_4 = \cdot 083\ W_L$

CENTRAL SPAN LOADED UNIFORMLY

3·3·6·3

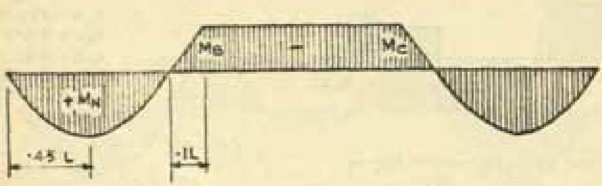
LIVE LOAD MOMENTS
$M_N = +\ 0{\cdot}075\ W_L L$
$M_B = M_C = -\ 0{\cdot}05\ W_L L$



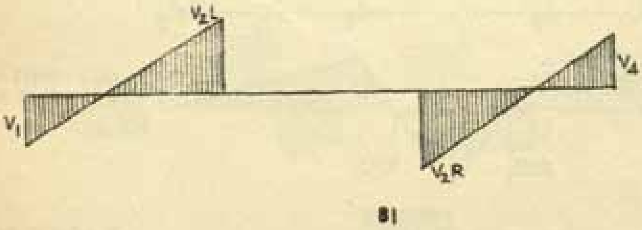
LIVE LOAD SHEARS
$V_1 = V_4 = 0{\cdot}05\ W_L$
$V_2R = V_3L = {\cdot}5\ W_L$

END SPANS LOADED UNIFORMLY

3·3·6·4

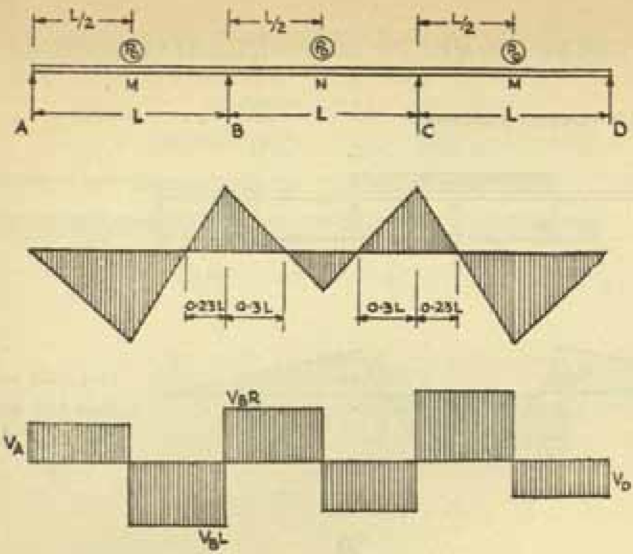


LIVE LOAD MOMENTS
$M_M = +\ 0{\cdot}101\ W_L L$
$M_B = M_C = -0{\cdot}05\ W_L L$



LIVE LOAD SHEARS
$V_1 = {\cdot}45\ W_L$
$V_{2L} = V_{2R} = {\cdot}55\ W_L$

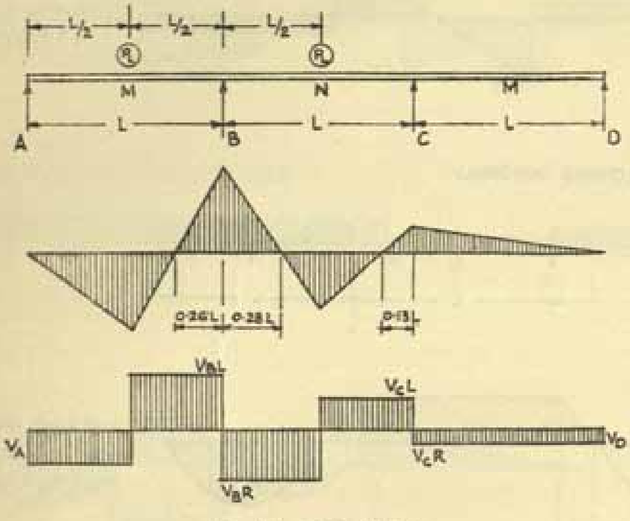
3·3·6·5



DEAD LOAD MOMENTS
$M_M = +0{\cdot}175\ P_D L$
$M_B = -0{\cdot}15\ P_D L$
$M_N = +0{\cdot}10\ P_D L$

$V_A = {\cdot}35\ P_D = V_D$
$V_B L = {\cdot}65\ P_D$
$V_B R = {\cdot}50\ P_D$

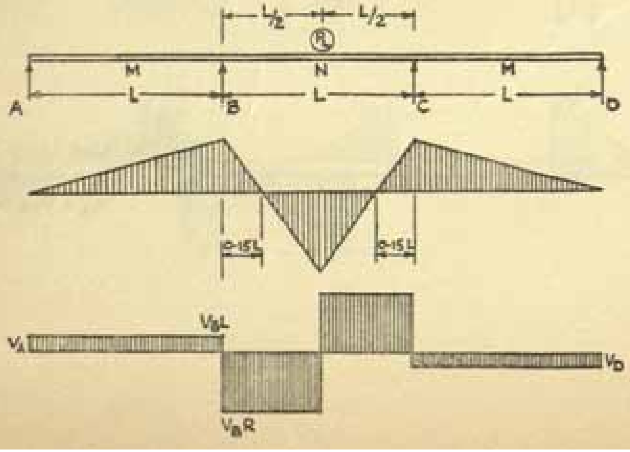
3·3·6·6



LIVE LOAD MOMENTS
$M_M = +0{\cdot}162\ P_L L$
$M_N = +0{\cdot}138\ P_L L$
$M_B = -0{\cdot}175\ P_L L$
$M_C = -0{\cdot}05\ P_L L$

$V_A = {\cdot}325\ P_L$
$V_B L = 0{\cdot}675\ P_L$
$V_B R = 0{\cdot}625\ P_L$
$V_C L = 0{\cdot}375\ P_L$
$V_C R = 0{\cdot}05\ P_L = V_D$

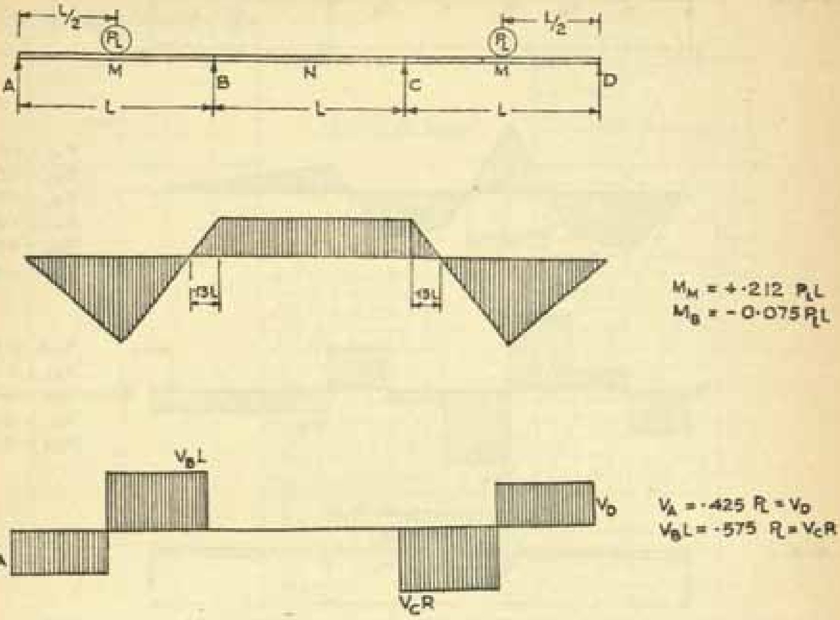
3·3·6·7



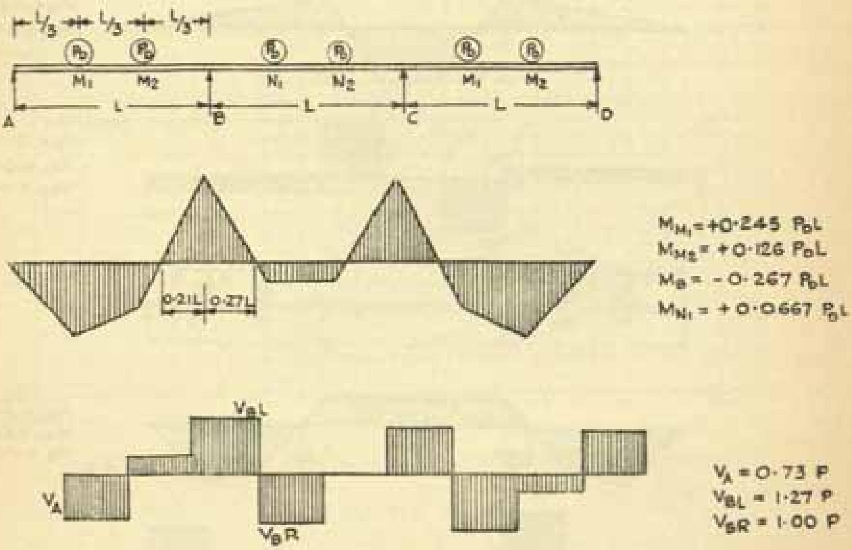
$M_B = -0{\cdot}075\ P_L L$
$M_N = +{\cdot}175\ P_L L$

$V_A = 0{\cdot}075\ P_L L = V_D$
$V_B L = 0{\cdot}075\ P_L = V_C R$
$V_B R = 0{\cdot}5\ P_L = V_C L$

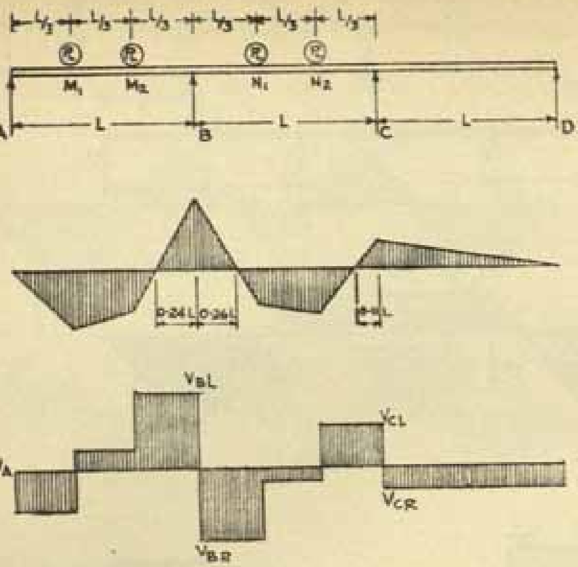
3·3·6·8


L/2
P_L
L/2
P_L
A
M
B
N
C
M
D
L
L
L
·13L
·13L
M_M = +·212 $P_L L$
M_B = −0·075 $P_L L$
$V_B L$
V_A
V_D
$V_C R$
V_A = ·425 P_L = V_D
$V_B L$ = ·575 P_L = $V_C R$

3.3.6.9


L/3
L/3
L/3
P_D
P_D
P_L
P_L
P_L
P_L
A
M_1
M_2
B
N_1
N_2
C
M_1
M_2
D
L
L
L
0·21L
0·27L
M_{M_1} = +0·245 $P_D L$
M_{M_2} = +0·126 $P_D L$
M_B = −0·267 $P_D L$
M_{N_1} = +0·0667 $P_D L$
$V_B L$
V_A
$V_B R$
V_A = 0·73 P
V_{BL} = 1·27 P
V_{BR} = 1·00 P

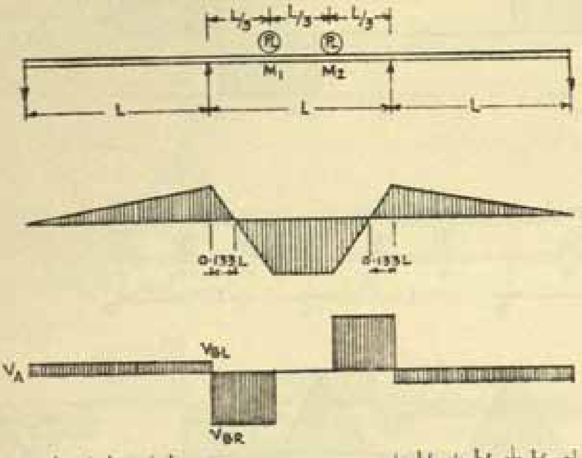
3.3.6.10



$M_{M_1} = +0.229\ P_L L$
$M_{M_2} = +0.126\ P_L L$
$M_B = -0.311\ P_L L$
$M_{N_1} = +0.096\ P_L L$
$M_{N_2} = +0.170\ P_L L$
$M_C = -0.089\ P_L L$

$V_A = 0.689\ P_L$
$V_{BL} = 1.311\ P_L$
$V_{BR} = 1.222\ P_L$
$V_{CL} = 0.778\ P_L$
$V_{CR} = 0.089\ P_L$

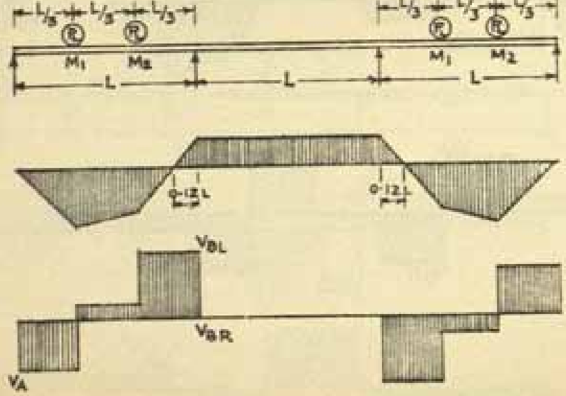
3.3.6.11



$M_B = -0.133\ P_L L$
$M_{M_1} = +0.2\ P_L L$

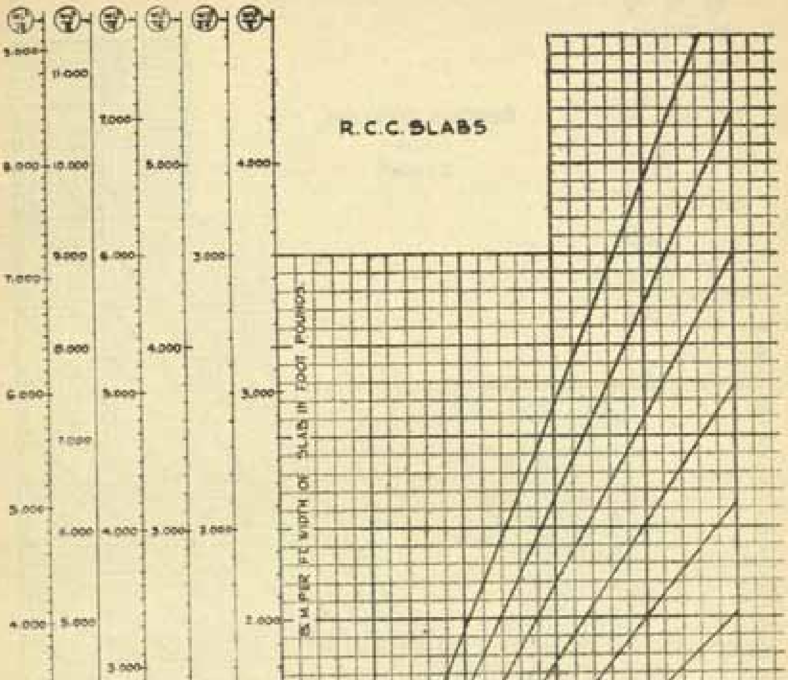
$V_A = 0.133\ P_L$
$V_{BL} = 0.133\ P_L$
$V_{BR} = 1.0\ P_L$

3.3.6.12



$M_{M_1} = +0.289\ P_L L$
$M_{M_2} = +0.245\ P_L P$
$M_B = -0.133\ P_L L$

$V_A = 0.867\ P_L$
$V_{BL} = 1.133\ P_L$
$V_{BR} = 0.00\ P_L$



B.M.S. PER FOOT WIDTH OF SLABS IN FOOT POUNDS FOR VARIOUS CONDITIONS OF ENDS

Fig. 3-1

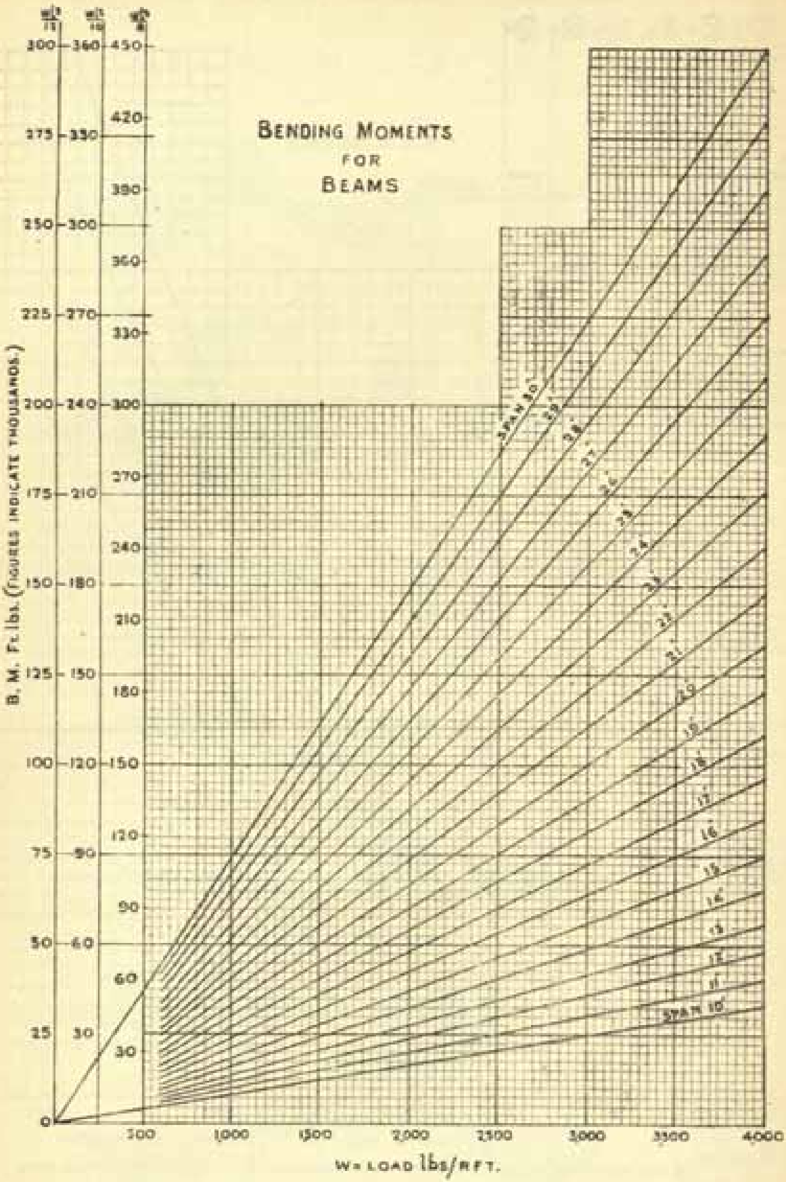

BENDING MOMENTS
FOR
BEAMS
B. M. Ft. lbs. (FIGURES INDICATE THOUSANDS.)
W = LOAD lbs/R F T.
SPAN 30'
SPAN 10'

Fig. 3–2

3.4 B. Ms. FOR R.C.C. SLABS
(Ready Calculated)

TABLE 3a

L \ W		40	60	80	100	120	140	160	180	200	220	240	260	280	300	320	340	360	380	400	420	440	460	480	500
4	$wl^2/8$	80	120	160	200	240	280	320	360	400	440	480	520	560	600	640	680	720	760	800	840	880	920	960	1000
	$wl^2/10$	64	9	128	160	192	224	256	288	320	352	384	416	448	480	512	544	576	608	640	672	704	736	768	800
	$wl^2/12$	53·33	80	106·7	133·3	160	186·7	213·3	240	266·7	293·3	320	346·7	373·3	400	426·7	453·3	480	506·7	533·3	560	586·7	613·3	640	666·7
5	$wl^2/8$	125	187·5	250·0	310·5	375	437·5	500	562·5	625	687·5	750	812·5	875	937·5	1000	1062·5	1125	1187·5	1250	1312·5	1375	1437·5	1500	1562·5
	$wl^2/10$	100	150	200	250	300	350	400	450	500	550	600	650	700	750	800	850	900	950	1000	1050	1100	1150	1200	1250
	$wl^2/12$	83·33	125	166·7	208·3	250	291·7	333·3	375	416·7	458·3	500	541·7	583·3	625	666·7	708·3	750	791·7	833·3	875	916·6	958·3	1000	1041·7
6	$wl^2/8$	180	270	360	450	540	630	720	810	900	990	1080	1170	1260	1350	1440	1530	1620	1710	1800	1890	1980	2070	2160	2250
	$wl^2/10$	144	216	288	360	432	504	576	648	720	792	864	936	1008	1080	1152	1224	1296	1368	1440	1512	1584	1656	1728	1800
	$wl^2/12$	120	180	240	300	360	420	480	540	600	660	720	780	840	900	960	1020	1080	1140	1200	1260	1340	1380	1440	1500
7	$wl^2/8$	245	367·5	490	612·5	735	857·5	980	1102·5	1225	1347·5	1470	1592·5	1715	1837·5	1960	2082·5	2205	2327·5	2450	2572·5	2695	2817·5	2940	3062·5
	$wl^2/10$	196	294	392	490	588	686	784	882	980	1078	1176	1274	1372	1470	1568	1666	1764	1862	1960	2058	2156	2254	2352	2450
	$wl^2/12$	163·2	245	326·6	408·3	490	571·6	653·3	735	816·6	898·3	979·9	1061·6	1143·2	1224·9	1306·6	1388·2	1469·9	1551·6	1633·2	1714·9	1796·5	1878·2	1959·8	2041·5
8	$wl^2/8$	320	480	640	800	960	1120	1280	1440	1600	1760	1920	2080	2240	2400	2560	2720	2880	3040	3200	3360	3520	3680	3840	4000
	$wl^2/10$	256	384	512	640	768	896	1024	1152	1280	1408	1536	1664	1792	1920	2048	2176	2304	2432	2560	2688	2816	2944	3072	3200
	$wl^2/12$	213·33	320	426·6	533·3	640	746·6	853·2	960	1066·6	1173·2	1280	1386·6	1493·2	1600	1706·7	1813·3	1920	2026·6	2133·3	2240	2346·7	2453·3	2559·9	2666·5
9	$wl^2/8$	405	607·5	810	1012·5	1215	1417·5	1620	1822·5	2025	2227·5	2430	2632·5	2835	3037·5	3240	3442·5	3341·3	3847·5	4050	4252·5	4455	4657·5	4860	5082·5
	$wl^2/10$	324	486	648	810	972	1134	1296	1458	1620	1782	1944	2106	2268	2430	2592	2754	2916	3078	3240	3402	3564	3726	3888	4050
	$wl^2/12$	270	405	540	675	810	945	1080	1215	1350	1485	1620	1755	1890	2025	2160	2295	2430	2545	2700	2835	2970	3105	3240	3375
10	$wl^2/8$	500	750	1000	1250	1500	1750	2000	2250	2500	2750	3000	3250	3500	3750	4000	4250	4500	4750	5000	5250	5500	5750	6000	6250
	$wl^2/10$	400	600	800	1000	1200	1400	1600	1800	2000	2200	2400	2600	2800	3000	3200	3400	3600	3800	4000	4200	4400	4600	4800	5000
	$wl^2/12$	333·3	500	666·6	833·3	1000	1166·6	1333·3	1500	1666·6	1833	1999·9	2166·6	2333·2	2500	2666·7	2833·3	3000	3166·6	3333	3499·7	3666	3833	3999·6	4166·5
11	$wl^2/8$	605	907·5	1210	1512·5	1815·5	2117·5	2420	2722·5	3025	3327·5	3630	3932·5	4235	4537·5	4840	5142·5	5445	5747·5	6050	6352·5	6655	6957·5	7260	7562·5
	$wl^2/10$	484	726	968	1210	1452	1694	1936	2178	2420	2662	2904	3146	3386	3630	3872	4114	4356	4598	4840	5082	5324	5566	5808	6050
	$wl^2/12$	403·3	605	806·6	1008·3	1210	1411·6	1613·2	1815	2016·6	2218·2	2420	2621·6	2923·2	3025	3226·7	3428·3	3630	3831·6	4033	4234·7	4436·3	4638	4839·6	5041·5
12	$wl^2/8$	720	1080	1440	1800	2160	2520	2880	3240	3600	3960	4320	4680	5080	5400	5760	6120	6480	6880	7200	7560	7920	8280	8640	9000
	$wl^2/10$	576	864	1152	1440	1728	2166	2304	2592	2880	3168	3456	3744	4032	4320	4608	4896	5184	5472	5760	6048	6256	6624	6912	7200
	$wl^2/12$	480	720	960	1200	1440	1680	1920	2160	2400	2640	2880	3120	3360	3600	3840	4080	4320	4560	4800	5040	5280	5550	5760	6000
13	$wl^2/8$	845	1267·5	1690	2112·5	2535·0	2957·5	3380	3802·5	4225	4647·5	5070	5492·5	5915·0	6337·5	6760	7182·5	7635	8027·5	8450	8872	9295	9717·5	10140	10562·5
	$wl^2/10$	676	1014	1352	1690	2028	2366	2704	3042	3380	3718	4056	4394	4732	5070	5408	5746	6084	6322	6760	7098	7436	7774	8112	8450
	$wl^2/12$	563·33	845	1126·7	1408·3	1690	1971·6	2253·3	2535	2816·6	3098·3	3379·9	3661·7	3943·3	4225	4560·7	4788·3	5070	5351·7	5633·3	5915	6196·6	6478·3	6760	7041·5
14	$wl^2/8$	976	1464	1952	2440	2928	3416	3904	4392	4880	5368	5856	6344	6832	7320	7808	8296	8784	9272	9760	10248	10736	11224	11712	12200
	$wl^2/10$	784	1176	1568	1960	2352	2744	3136	3528	3920	4312	4704	5096	5488	5880	6272	6664	7076	7448	7840	8232	8624	9016	9408	9800
	$wl^2/12$	653·3	980	1306·6	1633	1960	2286·6	2613·3	2940	3266·7	3593·3	3920	4246·7	4573·3	4900	5226·6	5555·3	5880	6206·6	6533·3	6860·0	7186·6	7513·3	7840	8166·7

BENDING MOMENTS (IN POUNDS FEET) FOR SLABS

L=SPAN IN FEET W=LOAD PER SQ. FOOT

TABLE 3-b

Values of bending moments for beams in ft/pounds

$$M = \frac{WL}{12}$$

W \ L	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	
1000	8333	10083	12000	14083	16333	18750	21333	24083	27000	30083	33333	36750	40333	44083	48000	52083	56333	60750	65333	70083	75000	1000
1100	9466	11166	13200	15491	17999	20625	23466	26481	29700	33091	36667	40425	44366	48491	52800	57291	61966	66825	71866	77091	82500	1100
1200	10000	12100	14400	16900	19600	22500	25600	28900	32400	36100	40000	44100	48400	52900	57600	62500	67600	72900	78400	84100	90000	1200
1300	10833	13108	15600	18308	21233	24375	27733	31308	35100	39108	43333	47775	52433	57308	62400	67708	73233	78975	84933	91108	97500	1300
1400	11666	14116	16800	19716	23266	26250	29866	33716	37800	42116	46667	51450	56466	61716	67200	72916	78866	85050	91466	98116	105000	1400
1500	12500	15125	18000	21125	24500	28125	32000	36125	40500	45125	50000	55125	60500	66125	72000	78005	84500	91125	97900	105125	112500	1500
1600	13333	16133	19200	22533	26133	30000	34133	38533	43200	48133	53333	58800	64533	70533	76800	83333	90133	97200	104533	112133	120000	1600
1700	14166	17141	20400	23941	27766	31875	36266	40941	45900	51141	56666	62475	68566	74941	81600	88541	95766	103275	110866	119141	127500	1700
1800	15000	18150	21600	25350	29400	33750	38400	43349	48600	54150	60000	66150	72600	79350	86400	93750	101400	109350	117600	126150	135000	1800
1900	15833	19158	22800	26758	31033	35625	40533	45758	51300	57158	63333	69825	76633	83758	91200	98958	107033	115425	124133	133158	142500	1900
2000	16666	20166	24000	28166	32333	37500	42666	48166	54000	60166	66667	73500	80667	88166	96000	104166	112667	121500	130667	140166	150000	2000
2100	17500	21249	25200	29574	33966	39375	44800	50574	56700	63174	70000	77175	84700	92574	100800	109374	118300	127575	137200	147174	157500	2100
2200	18333	22183	26400	30983	35600	41250	46933	52983	59400	66183	73334	80850	88734	96983	105600	114583	123934	133650	143734	154183	165000	2200
2300	19166	23191	27600	32391	37233	43125	49066	55391	62100	69191	76667	84525	92767	101391	110400	119791	129567	139725	150267	161191	172500	2300
2400	20000	24199	28800	33749	39200	45000	51200	57800	64800	72200	80000	88200	96800	105800	115200	125000	135200	145800	156800	168200	180000	2400
2500	20833	25208	30000	35208	40500	46875	53333	60208	67500	75208	83333	91875	100834	110208	120000	130208	140834	151875	163234	175208	187500	2500
2600	21666	26216	31200	36618	42133	48750	55466	62616	70200	78216	86667	95550	104867	114616	124800	135416	146467	157950	169867	182216	195000	2600
2700	22500	27224	32400	38024	43766	50625	57600	65024	72900	81224	90000	99225	108900	118704	129600	140624	152100	164025	176200	189224	202500	2700
2800	23333	28233	33600	39433	45399	52500	59733	67432	75600	84233	93334	102900	112934	123433	134400	145832	157734	170100	182934	196233	210000	2800
2900	24166	29241	34800	40841	47033	54375	61866	69841	78300	87241	96667	106575	116967	127841	139200	157041	163367	176175	189467	203241	217500	2900
3000	25000	30250	36000	42250	49000	56250	64000	72250	81000	90250	100000	110250	121000	132250	144000	156250	169000	182250	196000	210250	225000	3000
3100	25833	31333	37200	43658	50633	58125	66133	74650	83700	93258	103333	113925	125033	136658	148800	161458	174633	188325	202533	217258	232500	3100
3200	26667	32267	38400	45067	52266	60000	68267	77067	86400	96267	106667	117600	129067	141067	153600	166667	180267	194400	209067	224267	240000	3200
3300	27500	33275	39600	46475	53900	61875	70400	79475	89100	99275	100000	121275	133100	145475	158400	181875	185900	200475	215600	231275	247500	3300
3400	28333	34283	40800	47883	55933	63750	72533	81883	91800	102283	113333	124950	137133	149882	163200	177083	191533	206550	222133	238283	255000	3400
3500	29167	35292	42000	49292	57167	65625	74667	84290	94500	105292	116667	128625	141167	154292	168000	182292	197167	212625	228567	245292	262500	3500
3600	30000	36300	43200	50700	58800	67500	76800	86700	97200	108300	120000	132300	145200	158700	172800	187500	202800	218700	235200	252300	270000	3600
3700	30833	37308	44400	52108	60433	69375	78933	89108	99900	111308	123333	135975	149233	163108	173600	192708	208433	224775	241533	259308	277500	3700
3800	31667	38317	45600	53517	62066	71250	81067	91516	102600	113317	126667	139650	153267	167517	182400	197916	214067	230850	248267	266317	285000	3800
3900	32500	39325	46800	54925	62700	73125	83200	93925	105300	117325	130000	143325	157300	171925	187200	203125	219700	236925	254800	273325	292500	3900
4000	33333	40333	48000	56333	69332	75000	85333	96332	108000	120333	133333	147000	161333	176333	192000	208332	225334	243000	261333	280333	300000	4000

W = LOAD IN POUNDS PER R.FT. L = SPAN IN FEET.

CHAPTER 4

DESIGN OF R.C.C. SLABS

CONTENTS

CHAPTER 4

DESIGN OF R.C.C. SLABS

4.1 (a) FORMULA FOR DESIGN OF R.C.C. SLABS AND RECTANGULAR BEAMS.

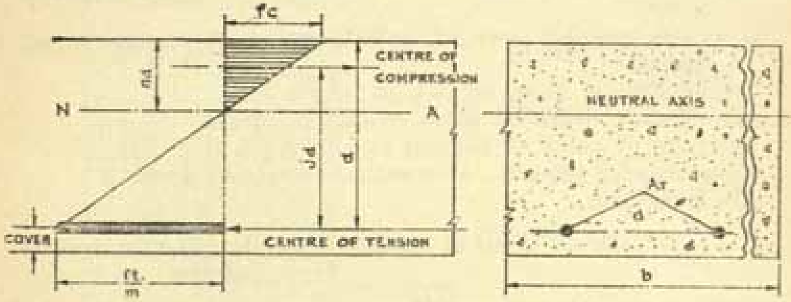


Fig. A

NOTATION.

fc=compressive unit stress in extreme fibre of concrete. The following values are adopted in practice for 1 : 2 : 4 concrete

fc= 600 lbs/ □″	Old L.C.C. Regulations
fc= 750 ,,	New L.C.C. By Laws (Ordinary Grade)
950 ,,	-do- (Quality A Grade)
fc= 750 ,,	D.S.I.R. or I.S.I. Code of Practice (Ordinary Grade)
950 ,,	-do- (High Grade)
1188 ,,	-do- (Special Grade)
1000 ,,	B. S. Code (Aggregates as per B.S. 882)
ft=16000 lbs/ □″	Old L.C.C. Regulations
=18000 ,,	New -do- D.S.I.R. & B.S. Codes
=20000 ,,	High Yield Point Mild Steel
=25000 ,,	Hard Drawn Steel Wire

m=modular ratio i.e. $\dfrac{\text{Modulus of elasticity of steel}}{\text{Modulus of elasticity of concrete}}$

The following values of m are assumed in practice:

m=15 (New & Old L.C.C.R.) and B.S. Code of Practice

$m=\frac{40,000}{3\,fc}\left\{\begin{array}{l}\text{D.S.I.R. Code of Practice}\\ \text{I.S.I. ,, ,, ,,}\end{array}\right\}$

i.e. m=17.78 for ordinary grade
=14.03 ,, High Grade
=11 ,, Special Grade.

R.M=Moment of resistance or bending moment in pounds inches

At=Cross-sectional area of re-inforcement in tension in sq. inches.

b=breadth of beam or slab in inches

d=effective depth of beam or slab in inches

n=ratio of depth of neutral axis to depth d

j=ratio of lever arm, of resisting couple to depth d

jd=lever arm

$p=\frac{At}{bd}$= ratio of area of tension steel to effective area of concrete

4.1 (b) DESIGN CONSTANTS & STRESSES.

(i) Stresses

	fc	ft	m	Ref	
Old L.C.C.R.	600	16000	15	(a)	
New L.C.C.R.					
Ordinary grade	750	18000	15	(b)	
Quality A grade	950	18000	15	(c)	
D.S.I.R. or ISI. Code of Practice Also Railway code of Practice					Also I.S.I. Code for 1:2:4 mix ordinary grade.
Ordinary grade	750	18000	18	(d)	
High grade	950	18000	14	(e)	
Special grade	1188	18000	11	(f)	
B.S. Code of Practice Aggregates according to B.S. 882	1000	18000	15	(g)	
Aggregates not according to B.S. 882	750	18,000	15	(h)	

(ii) Constants

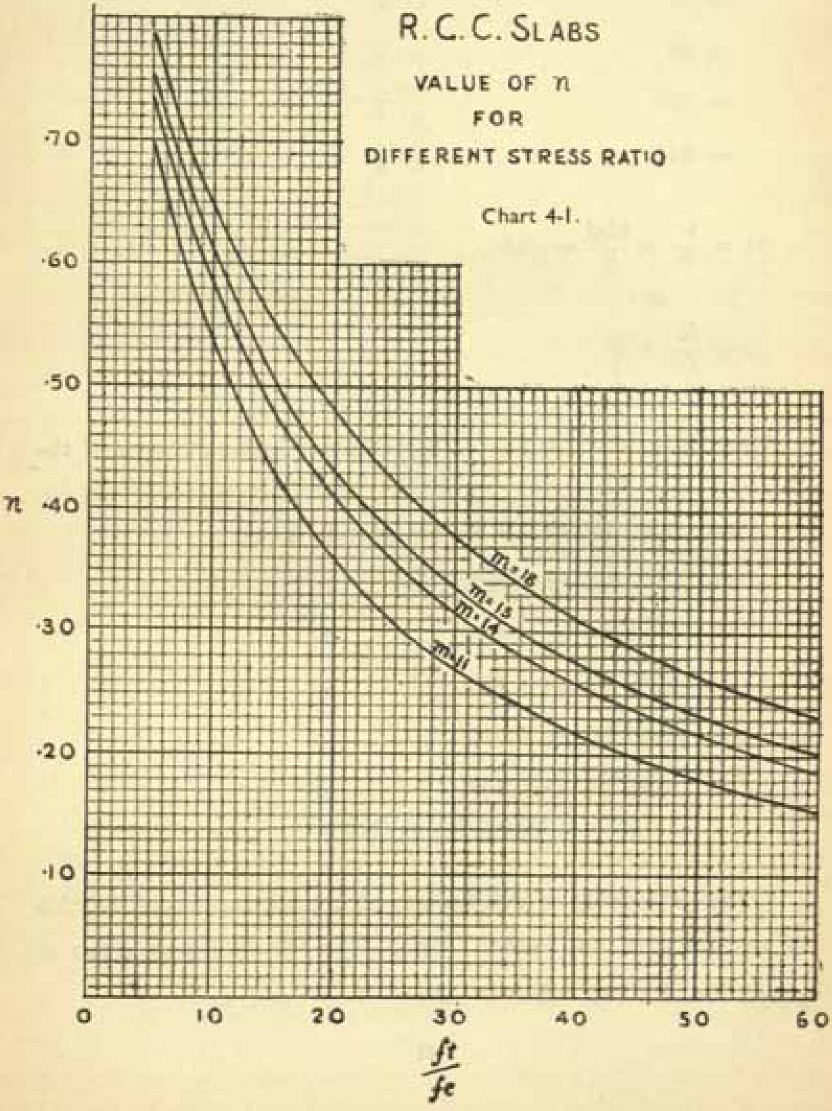
$$n=\frac{mfc}{mfc+ft}\text{ or }\frac{1}{1+\frac{ft}{mfc}}\quad\ldots\ldots\ldots\ldots\quad(1)$$

n = .36 for case a
= .385 ,, ,, b & h
= .44 ,, ,, c
= .430 ,, ,, d

=.430	for case e
=.423	" " f
=.455	" " g

The location of neutral axis is always governed by the stress ratio $\frac{ft}{fc}$ and modular ratio m.

The values of n for different values of ft/fc and m are given in graph No. 4-1.



$$j = 1 - \frac{n}{3} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (2)$$

$j = .88$	for case a
$= .87$	" " b & h
$= .853$	" " c
$= .86$	" " d
$= .86$	" " e
$= .858$	" " f
$= .848$	" " g

$$At = \frac{fc}{ft} \times \frac{nbd}{2} = pbd \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (3)$$

or

$$p = \frac{fc}{ft} \times \frac{n}{2}$$

At = .00675 bd or .675% of the effective sectional area of the section for case a

= .008 bd or .8 %	for case	b & h
= .0117 bd or 1.17%	" "	c
= .0089 bd or .89%	" "	d
= .0112 bd or 1.12%	" "	e
= .0140 bd or 1.40%	" "	f
= .0126 bd or 1.26%	" "	g

(b & d measured in inches)

The percentage of reinforcement depends upon the location of neutral axis and stress ratio. The value of p is given in graph No. 4-2 for different values of $\frac{ft}{fc}$ and m

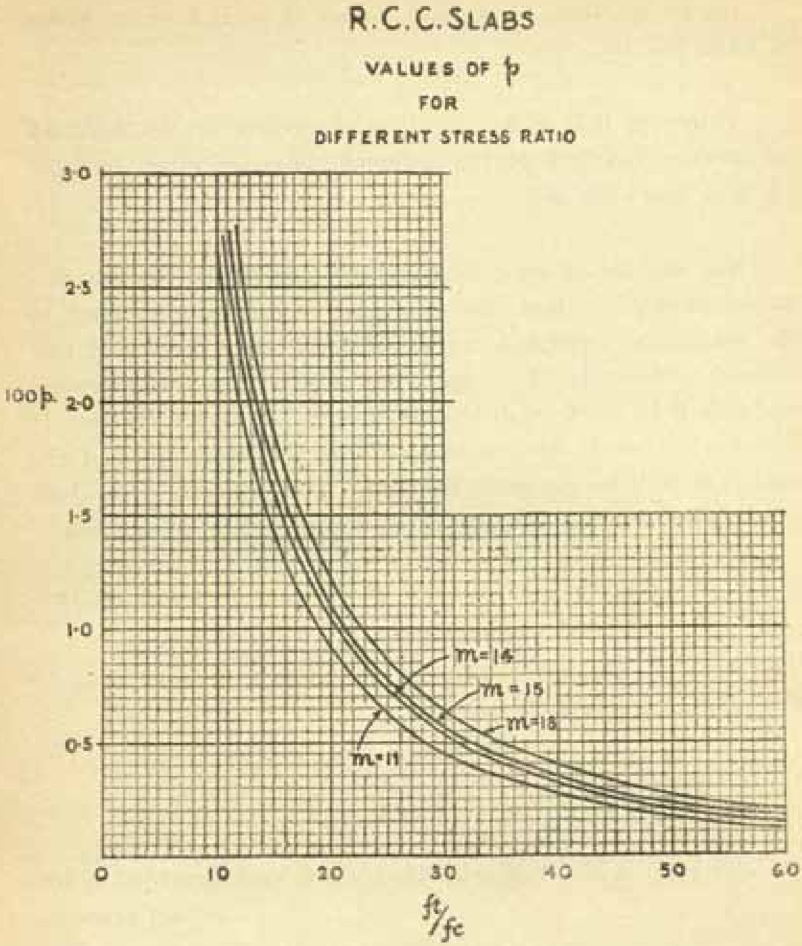


Chart 4-2.

$$\text{R.M.} = \left\{ \begin{array}{c} ft\ At\ jd \\ \text{or} \\ \frac{1}{2} fc\ nj\ bd^2 \end{array} \right. = Qbd^2 \text{ (b \& d measured in inches)} \quad \ldots\ldots\ldots \quad (4)$$
(inch pounds)

Q = 95	for case	a
126	„ „	b & h
179	„ „	c
137	„ „	d
173.3	„ „	e
217	„ „	f
192.8	„ „	g

Design constants for various values of fc, ft & m are given in table No. 4-a.

Values of R.M & At for slabs of various depths designed for stresses specified by the different codes are given in table 4-b and chart No. 4-3.

The amount of steel as given by formula (3) is the economic amount i.e. both the steel and concrete are stressed to the maximum permitted limits. If steel more than that calculated by formula (3) is used, the steel will be understressed and safe R.M. of the slab will be governed by the concrete. If less steel is used, the concrete will be understressed and the safe R.M. will be governed by steel. The following procedure is necessary to find the safe R.M. of the slab in such cases.

a. To find the neutral axis of the slab by the formula

$$n = \sqrt{p^2m^2 + 2\,pm} - pm$$

The values of n for m=11 to 18 & p=.002 to .02 are plotted in graph No. 4-3.

b. Find lever arm $j = d - \frac{n}{3}$

c. Find R.M. R.M.=At.ft.jd when steel provided is less than economic

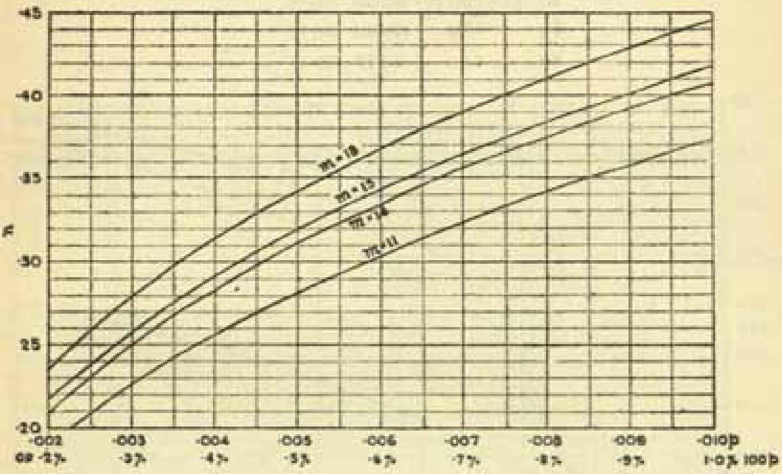
or $R.M. = \frac{fc}{2}\,nj\,bd^2$ when steel provided is more than economic

In general $R.M.=Qbd^2$

The different values of Q are given in graph No. 4-4 for different values of p & m=15 and m=18. R.M.s. for different depths of slab designed as per different codes and reinforced with different amount of steel are given in charts 4-5, 4-6 and 4-7.

R. C. C. SLAB

VALUES OF n FOR VARIOUS PERCENTAGES OF STEEL



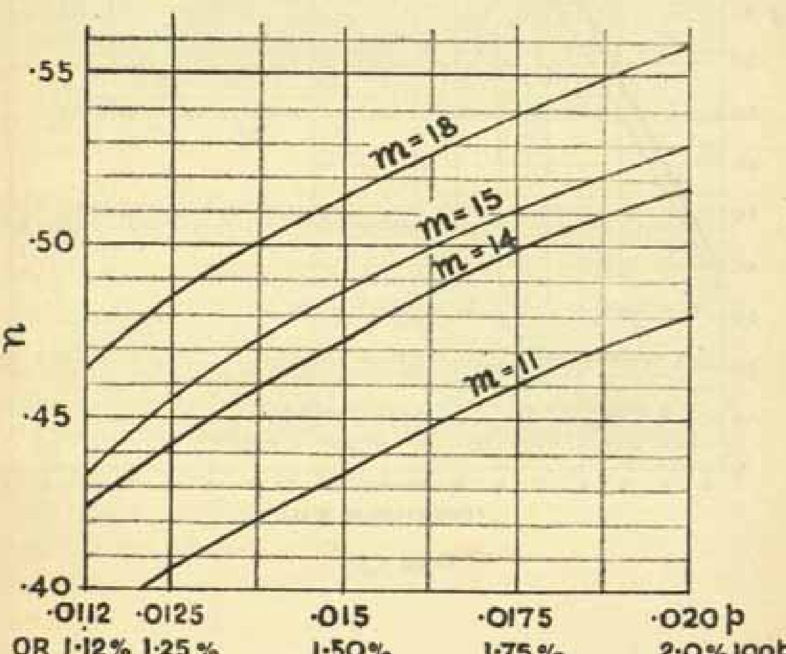


Chart 4–3

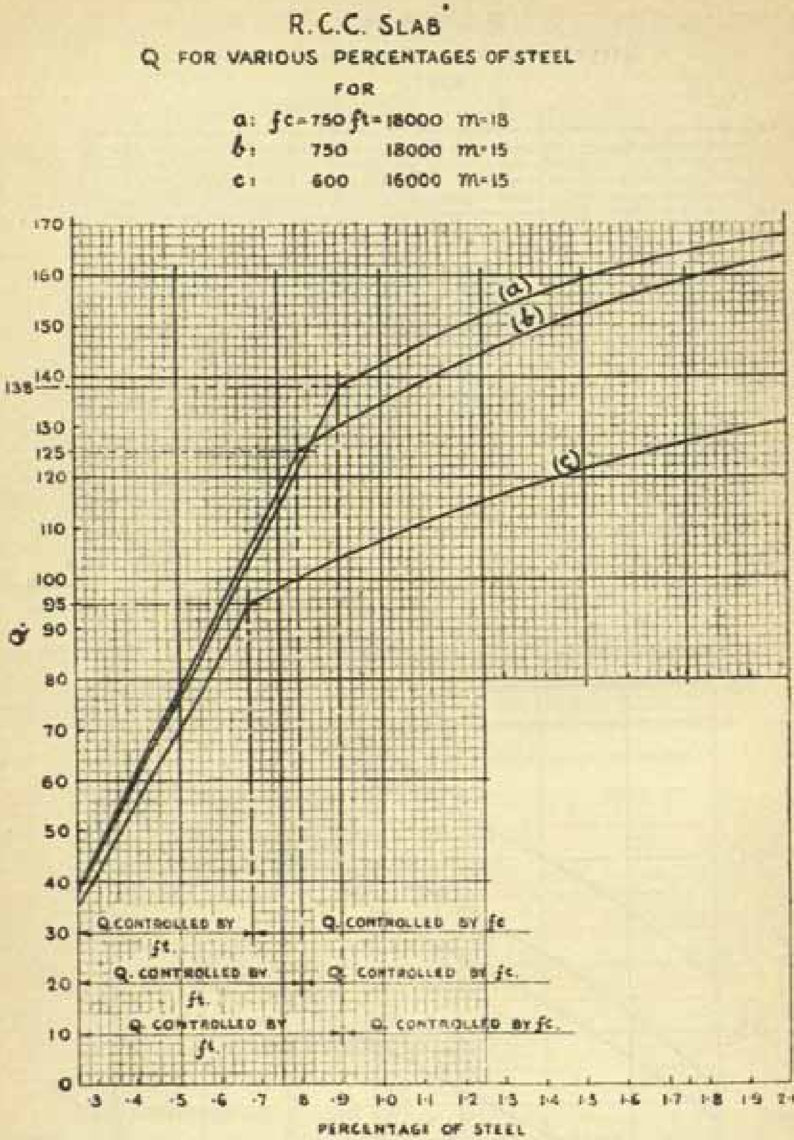

R.C.C. SLAB
Q FOR VARIOUS PERCENTAGES OF STEEL
FOR
a: fc=750 ft=18000 m=18
b: 750 18000 m=15
c: 600 16000 m=15
(a)
(b)
(c)
Q
Q CONTROLLED BY ft.
Q CONTROLLED BY fc
Q. CONTROLLED BY ft.
Q. CONTROLLED BY fc.
Q. CONTROLLED BY ft.
Q. CONTROLLED BY fc.
PERCENTAGE OF STEEL

Chart 4·4

R. C. C. SLABS

R. M. FOR VARIOUS AMOUNTS OF STEEL

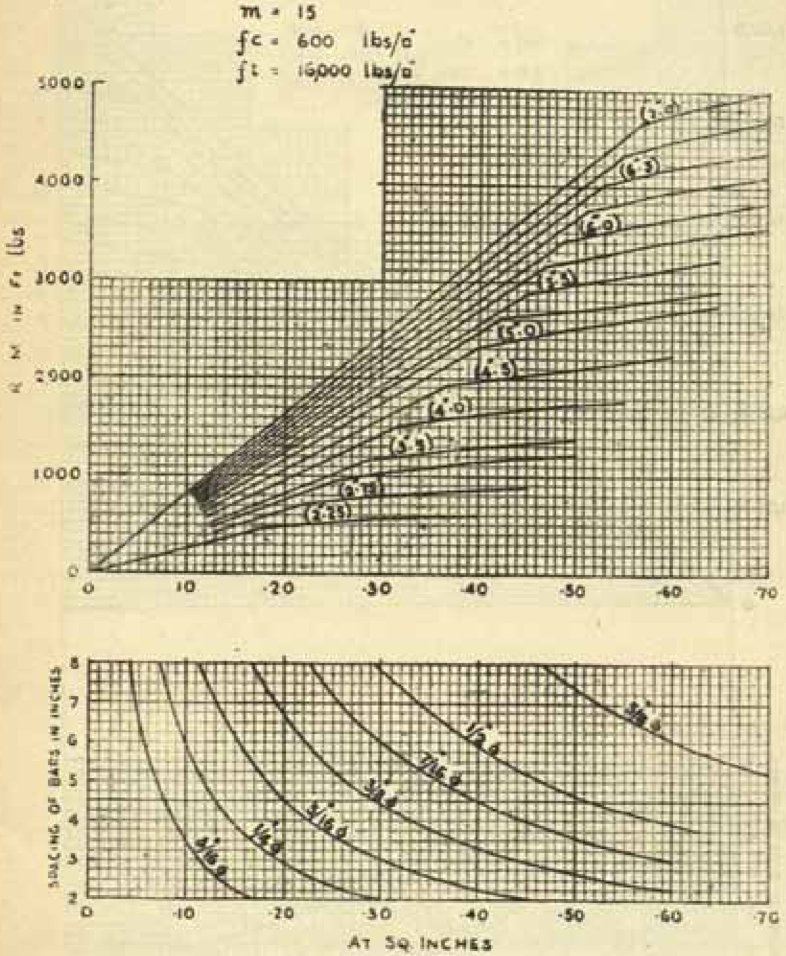


Chart 4-5

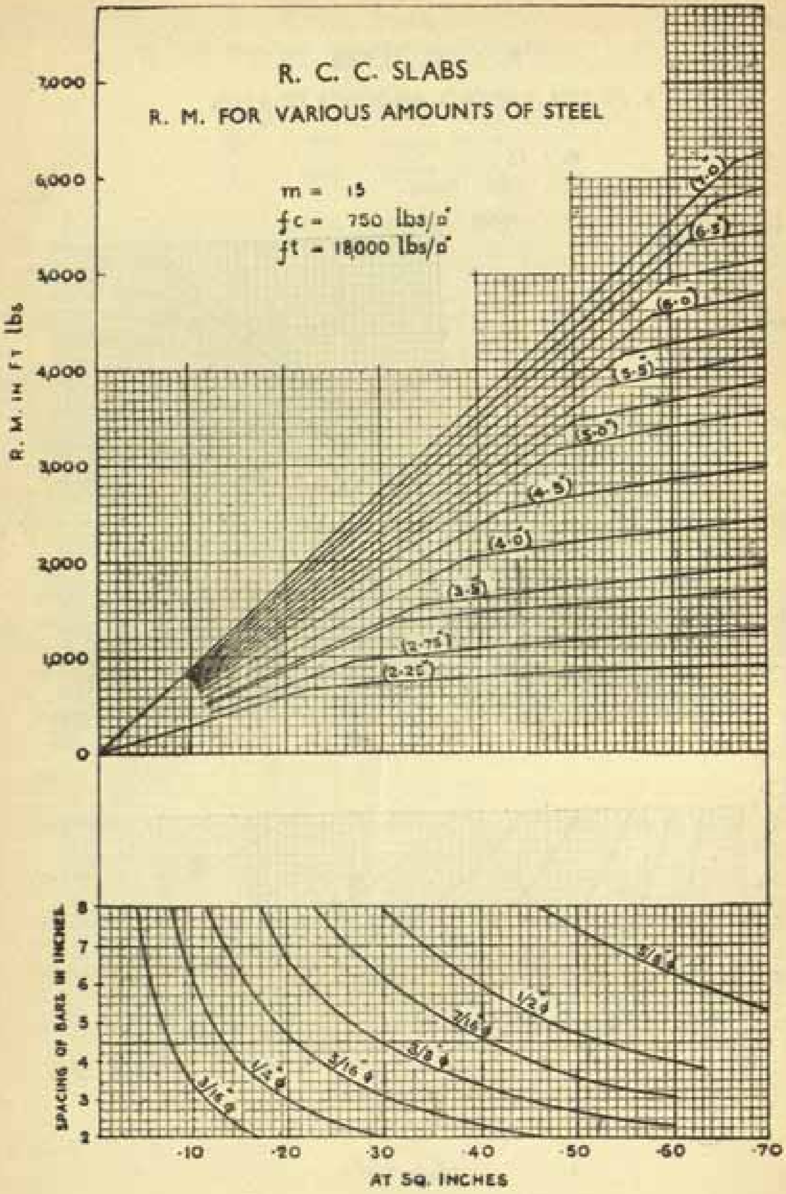

R. C. C. SLABS
R. M. FOR VARIOUS AMOUNTS OF STEEL
m = 15
fc = 750 lbs/□"
ft = 18,000 lbs/□"
R. M. IN FT lbs
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
(7·0")
(6·5")
(6·0")
(5·5")
(5·0")
(4·5")
(4·0")
(3·5")
(2·75")
(2·25")
SPACING OF BARS IN INCHES
8
7
6
5
4
3
2
5/8"φ
1/2"φ
7/16"φ
3/8"φ
5/16"φ
1/4"φ
3/16"φ
·10
·20
·30
·40
·50
·60
·70
AT SQ. INCHES

Chart 4-6

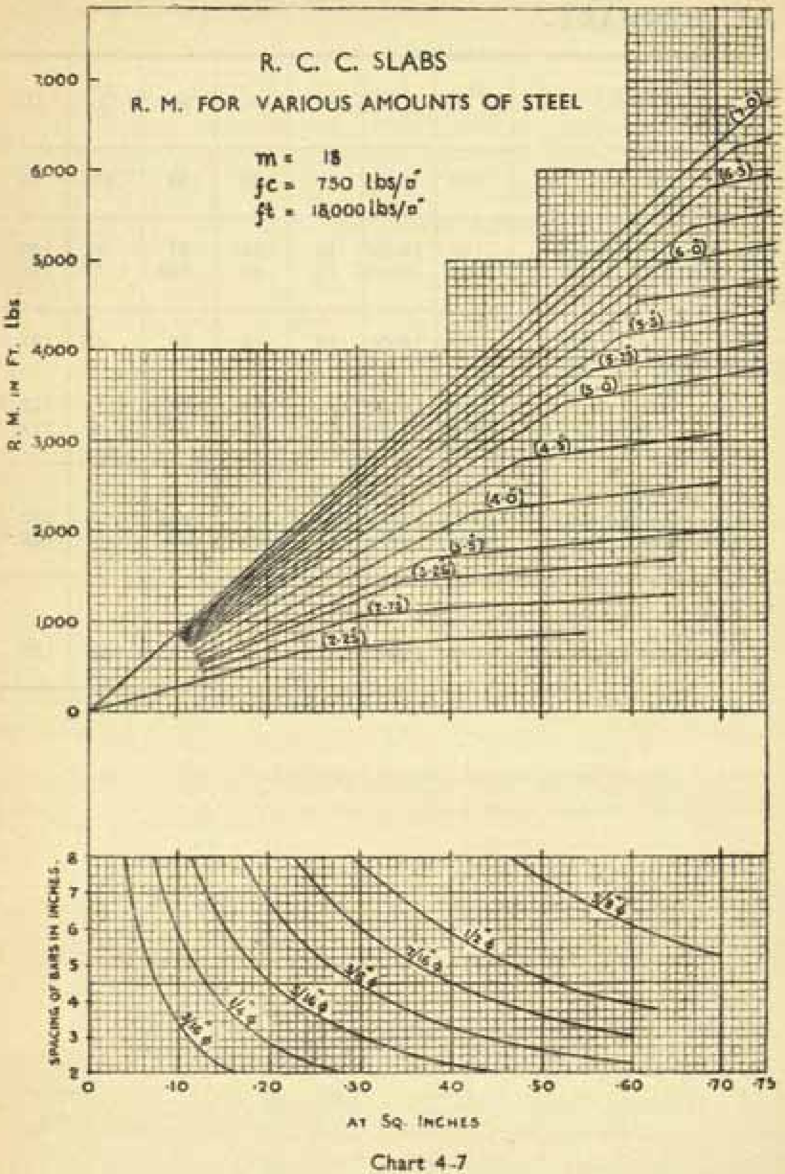

R. C. C. SLABS
R. M. FOR VARIOUS AMOUNTS OF STEEL
m = 18
fc = 750 lbs/□"
ft = 18,000 lbs/□"
R. M. IN FT. lbs
SPACING OF BARS IN INCHES.
AT SQ. INCHES

Chart 4-7

4.2 SUMMARY.

NAME	fc lbs/□"	ft lbs/□"	m	n	jd	At %	Q
Old L.C.C.R.	600	16000	15	.36	.88	.675	95
New L.C.C. Ordinary ..	750	18000	15	.385	.87	.8	126
Do A Grade ..	950	18000	15	.44	.853	1.17	179
D.S.I.R. Code Ordinary (Also Indian Railway Code)	750	18000	18	.43	.86	.89	137
Do. High Grade	950	18000	14	.43	.86	1.12	173.3
Do. Special Grade	1188	18000	11	.423	.858	1.40	217
B.S. Code of Practice Aggts as per B.S. 882 ..	1000	18000	15	.455	.848	1.26	192.8
Other aggts. ..	750	18000	15	.39	.87	.8	126
Proposed I.S. Code of Practice .. .. Ordinary Grade ..	750	18000	18	.43	.86	.89	137

TABLE 4-a.

VALUES OF DESIGN CONSTANTS FOR DIFFERENT VALUES OF fc. ft. & m.

fs	fc	m=15 q	m=15 p	m=15 n	m=15 j	m=18 q	m=18 p	m=18 n	m=18 j	m=14 q	m=14 p	m=14 n	m=14 j	fc	m=11 q	m=11 p	m=11 n	m=11 j
16000	400	49·6	·0034	·273	·909	55·5	·0039	·310	·897	47·5	·0032	·260	·913	600	79·1	·0055	·292	·903
	450	60·2	·0042	·297	·901	66·7	·0048	·335	·888	57·1	·0040	·285	·905	650	90·0	·0063	·309	·897
	500	71·3	·0050	·319	·894	79·2	·0056	·360	·880	68·4	·0048	·304	·899	700	101·2	·0071	·325	·892
	550	83·0	·0059	·340	·887	91·8	·0066	·383	·872	79·6	·0056	·325	·892	750	113·0	·0080	·340	·887
	600	95·0	·0068	·360	·880	104·7	·0076	·403	·866	91·1	·0064	·344	·885	800	125·2	·0089	·355	·882
	650	107·5	·0077	·379	·874	117·8	·0086	·422	·859	103·0	·0074	·363	·879	850	137·4	·0098	·369	·877
	700	120·4	·0087	·396	·868	131·3	·0096	·440	·853	116·3	·0083	·380	·873	900	150·0	·0107	·382	·872
	750	133·5	·0097	·413	·862	145·1	·0107	·456	·848	129·1	·0093	·396	·868	950	162·9	·0117	·395	·868
	800	146·9	·0107	·429	·857	159·1	·0118	·472	·843	142·2	·0103	·412	·863	1000	176·2	·0128	·407	·864
	850	160·6	·0118	·443	·852	174·0	·0130	·489	·837	155·6	·0114	·427	·858	1050	189·3	·0138	·419	·860
	900	174·5	·0129	·458	·847	188·4	·0141	·503	·832	169·1	·0124	·441	·853	1100	203·0	·0148	·431	·857
	950	188·6	·0140	·471	·843	203·5	·0154	·517	·828	183·2	·0135	·454	·849	1200	230·7	·0170	·452	·849
18000	400	45·8	·0028	·250	·917	51·5	·0032	·285	·905	43·7	·0026	·237	·921	600	73·3	·0045	·268	·911
	450	55·8	·0034	·273	·909	62·7	·0039	·311	·896	53·2	·0032	·259	·914	650	83·6	·0051	·284	·905
	500	66·3	·0041	·294	·902	74·1	·0046	·334	·889	63·5	·0039	·280	·907	700	94·4	·0058	·300	·900
	550	77·4	·0048	·314	·895	86·1	·0054	·354	·882	74·1	·0046	·299	·900	750	105·5	·0066	·314	·895
	600	88·9	·0056	·333	·889	98·2	·0062	·374	·875	85·4	·0053	·318	·894	800	116·9	·0073	·328	·891
	650	100·8	·0063	·351	·883	111·3	·0071	·394	·869	96·6	·0061	·336	·888	850	128·6	·0081	·342	·886
	700	113·1	·0072	·368	·877	124·6	·0080	·412	·863	108·9	·0069	·353	·882	900	140·9	·0089	·355	·882
	750	125·7	·0080	·385	·872	137·7	·0089	·428	·857	121·2	·0077	·368	·877	950	153·2	·0097	·367	·878
	800	138·7	·0089	·400	·867	151·6	·0099	·445	·852	133·0	·0085	·384	·872	1000	165·7	·0105	·379	·874
	850	151·9	·0098	·415	·862	165·4	·0108	·459	·847	146·0	·0094	·398	·867	1050	178·5	·0114	·391	·870
	900	165·3	·0107	·429	·857	180·0	·0119	·474	·842	159·0	·0103	·412	·863	1100	191·3	·0123	·402	·866
	950	179·0	·0117	·442	·853	194·0	·0128	·487	·838	173·3	·0112	·425	·858	1200	218·0	·0141	·423	·850
	1000	193·0	·0126	·455	·848	208·0	·0139	·500	·833	187·0	·0121	·438	·854					
20000	400	42·6	·0023	·231	·923	48·1	·0026	·264	·912	40·2	·0022	·219	·917	600	68·3	·0037	·248	·917
	450	52·0	·0028	·252	·916	58·5	·0032	·288	·904	49·8	·0027	·240	·920	650	78·3	·0043	·263	·912
	500	62·0	·0034	·273	·909	69·5	·0039	·311	·896	58·2	·0032	·259	·914	700	88·4	·0049	·278	·907
	550	72·5	·0040	·292	·903	81·0	·0046	·331	·890	69·3	·0038	·278	·907	750	98·9	·0055	·292	·903
	600	83·5	·0047	·310	·897	92·9	·0053	·356	·883	80·2	·0044	·296	·903	800	109·8	·0061	·306	·899
	650	94·9	·0053	·328	·891	105·2	·0060	·369	·877	91·1	·0051	·313	·896	850	121·0	·0068	·319	·894
	700	106·7	·0060	·344	·885	117·7	·0068	·386	·871	102·4	·0058	·329	·890	900	132·4	·0075	·331	·890
	750	118·8	·0068	·360	·880	130·8	·0076	·403	·866	114·2	·0065	·344	·885	950	144·4	·0082	·343	·886
	800	131·2	·0075	·375	·875	144·0	·0084	·419	·860	126·3	·0072	·359	·880	1000	156·4	·0089	·355	·882
	850	144·0	·0083	·389	·870	157·8	·0092	·434	·855	138·6	·0079	·373	·876	1050	168·8	·0096	·366	·878
	900	157·0	·0091	·403	·866	172·0	·0101	·448	·851	151·7	·0087	·387	·871	1100	181·3	·0104	·377	·874
	950	170·2	·0099	·416	·861	185·5	·0109	·461	·846	164·5	·0091	·396	·867	1200	206·8	·0119	·398	·868

TABLE 4-b.

RM & At for R.C.C. slabs of various depths for different mixes.

MIX	"a"		"b & h"		c		d		e		f		g	
d Inches	R.M. (Ft. lbs.)	At (□")	R. M.	At	R. M.	At	R. M.	At	R. M.	At	R. M.	At	R. M.	At
2.25	481	.182	638	.216	906	.315	699	.240	877	.302	1103	.381	977	.340
2.75	728	.223	953	.264	1354	.386	1644	.294	1331	.370	1649	.465	1459	.416
3.25	1003	.263	1350	.312	1890	.456	1457	.347	1330	.437	2290	.550	2038	.491
3.50	1164	.283	1543	.336	2183	.491	1690	.374	2123	.470	2671	.592	2364	.529
4.00	1520	.324	2016	.384	2864	.562	2208	.427	2773	.538	3488	.677	3088	.605
4.50	1924	.365	2550	.432	3625	.632	2795	.480	3509	.605	4415	.761	3907	.680
5.00	2375	.405	3150	.480	4475	.702	3450	.534	4333	.672	5450	.846	4823	.756
5.25	2618	.425	3473	.504	4933	.737	3803	.560	4776	.706	6008	.888	5319	.794
5.50	2874	.446	3812	.528	5415	.772	4175	.587	5242	.739	6595	.930	5838	.832
5.75	3141	.465	4166	.552	5917	.807	4563	.614	5729	.773	7207	.973	6381	.869
6.00	3340	.486	4536	.576	6484	.842	4968	.641	6279	.806	7848	1.02	6948	.907
6.25	3611	.506	4922	.600	6992	.878	5390	.668	6769	.841	8515	1.06	7539	.945
6.50	4013	.527	5324	.624	7563	.913	5830	.694	7322	.874	9210	1.10	8154	.983
6.75	4327	.547	5740	.648	8165	.948	6283	.721	7906	.907	9932	1.14	8793	1.020
7.00	4655	.564	6174	.672	8771	.983	6762	.748	8512	.940	10682	1.18	9457	1.058

Note.—For d not given in the Table above. Refer to Chart No. 4-8.

Table 4-c.

R.C.C. SLABS

Simply supported slabs (fc—600, ft.—16000, m—15)

Total Depth of Slab (Inches)	SAFE LOAD (INCLUDING WEIGHT OF SLAB) Lbs./□ Ft. SPAN IN FEET													DETAILS OF SLABS							
														Effective Depth "d"	Area of Steel/Ft. AT	Cover Inches	Moment of Resistance Foot lbs. R.M.	REINFORCEMENT (round bars)		QUANTITIES Per 100 s.ft.	
	4'	5'	6'	7'	8'	9'	10'	11'	12'	13'	14'	15'	16'					Main*	Distribution	Concrete C. Ft.	Steel Cwts.
3"	238	152	106	78	60	47								2·25	·181	9/16	481	1/4" @ 3"	3/16" @ 9"	25·00	0·75
3½"		238	158	116	89	70	57							2·75	·221	9/16	718	3/8" @ 5½"	„ 10"	29·17	0·92
4"		318	221	162	124	98	80	66						3·25	·253	9/16	1003	„ 5"	1/4" @ 12"	33·33	1·05
4½"		372	258	190	145	115	93	76						3·50	·282	13/16	1163	„ 4½"	1/4" @ 14"	37·50	1·14
5"		484	336	248	189	149	121	100	84	72				4·00	·324	13/16	1520	„ 4"	1/4" @ 15"	41·67	1·25
5½"				312	239	189	153	126	106	90	78			4·50	·365	3/4	1924	„ 3½"	Do	45·83	1·40
6"				385	295	233	189	156	137	112	96	82		5·00	·405	3/4	2375	1/2" @ 6"	Do.	50·00	1·45
6¼"				425	325	257	208	172	144	122	106	93	81	5·25	·425	3/4	2618	„ 5½"	1/4" @ 14"	52·08	1·60
6½"				470	359	284	230	190	160	137	118	102	90	5·50	·446	3/4	2874	„ 5"	1/4" @ 12"	54·17	1·75
6¾"				508	389	307	249	205	173	147	127	110	97	5·75	·465	3/4	3141	„ 5"	Do.	56·25	1·75
7"				557	427	337	274	226	190	161	139	121	107	6·00	·486	3/4	3420	„ 5"	Do.	58·33	1·75
7¼"				602	460	364	295	244	204	174	150	132	116	6·25	·506	3/4	3710	„ 4½"	Do.	60·42	1·90
7½"				655	500	396	321	266	223	190	164	142	125	6·50	·527	3/4	4013	„ 4½"	1/4" @ 10"	62·50	2·00
7¾"				702	538	425	344	284	239	202	175	154	135	6·75	·547	3/4	4328	„ 4"	Do.	64·58	2·12
8"				760	530	460	372	307	258	220	190	165	145	7·00	·567	11/16	4655	„ 4"	Do.	66·67	2·13

* Bar Spacings have been kept at round figures though theoretical values may be slightly different.

Table 4-d.

R.C.C. SLABS

Simply supported slabs (fc—750, ft—18,000, m—15)

Total Depth of Slab (Inches.)	SAFE LOAD (INCLUDING WEIGHT OF SLAB) Lbs/□ Ft. SPAN IN FEET													DETAILS OF SLABS				REINFORCEMENT (round bars)		QUANTITIES Per 100 s.ft	
	4′	5′	6′	7′	8′	9′	10′	11′	12′	13′	14′	15′	16′	Effective Depth (Inches) d	Area of Steel/Ft. Ar	Cover (Inches)	Moment of Resistance Foot Lbs. R.M.	Main	Distribution	Concrete C. Ft.	Steel Cwts.
3″		204	142	104	80	63	51	42						2·25	·216	9/16	638	3/8″ @ 5½″	1/4″ @ 9″	25·00	1·03
3½″			210	155	119	94	76	63	53	45				2·75	·264	9/16	953	″ 4½″	1/4″ @ 10″	29·17	1·18
4″			296	217	167	133	106	87	74	63				3·25	·312	9/16	1350	″ 4″	1/4″ @ 12″	33·33	1·25
4½″			343	253	194	153	124	103	86	73	63			3·50	·336	3/4	1543	″ 3¾″	1/4″ @ 14″	37·50	1·42
5″					252	196	161	136	112	96	82			4·00	·384	3/4	2016	1/2″ @ 6″	1/4″ @ 15″	41·67	1·46
5½″					320	250	204	168	142	120	102	90	80	4·50	·432	3/4	2550	″ 5½″	1/4″ @ 14″	45·83	1·58
6″					394	310	252	208	176	150	129	112	98	5·00	·480	3/4	3150	″ 5″	1/4″ @ 12″	50·00	1·75
6¼″					435	345	280	230	195	166	143	127	108	5·25	·504	3/4	3473	″ 4¾″	1/4″ @ 12″	52·08	1·90
6½″					478	376	305	256	212	180	155	136	119	5·50	·528	3/4	3812	″ 4½″	1/4″ @ 12″	54·17	1·90
6¾″					520	410	334	275	232	196	170	148	130	5·75	·552	3/4	4166	1/2″ @ 4″	1/4″ @ 11″	56·25	2·12
7″						446	363	300	251	214	185	161	143	6·00	·576	3/4	4536	1/2″ @ 4″	1/4″ @ 10″	58·33	2·13
7¼″						490	396	325	275	234	200	175	154	6·25	·600	3/4	4922	1/2″ @ 4″	1/4″ @ 10″	60·42	2·13
7½″						525	426	350	295	252	217	189	166	6·50	·624	11/16	5324	5/8″ @ 6″	1/4″ @ 10	62·50	2·30
7¾″						570	460	380	320	270	235	203	180	6·75	·648	11/16	5740	5/8″ @ 5½″	1/4″ @ 9″	64·58	2·55
8						610	494	407	342	232	250	219	194	7·00	·672	11/16	6174	5/8″ @ 5½″	1/4″ @ 9″	66·67	2·56

Table 4-c.
R.C.C. SLABS
Simply supported slabs (fc—750, ft—18000, m—18)

Total Depth, of Slab (inches).	SAFE LOAD (INCLUDING WEIGHT OF SLAB) Lbs./□ Ft. SPAN IN FEET													● DETAILS OF SLABS ●							
														Effective Depth (inches) d	Area of Steel/Ft. AT	Cover (inches)	Moment of Resistance Foot Lbs. R.M.	REINFORCEMENT (round bars)		QUANTITIES Per 100 s.ft.	
	4′	5′	6′	7′	8′	9′	10′	11′	12′	13′	14′	15′	16′					Main	Distribution	Concrete C. Ft.	Steel Cwts.
3"			155	114	87	69	56	46						2·25	·240	9/16	609	3/8" @ 5½"	1/4" @ 10"	25·00	1·03
3½"			231	171	131	104	83	69	58	51	43			2·75	·294	9/16	1044	3/8" @ 4½"	Do.	29·17	1·18
4"				240	182	144	117	98	81	69	60			3·25	·347	9/16	1457	1/2" @ 6½"	1/4" @ 9"	33·33	1·42
4½"				277	211	167	136	114	95	84	69	60		3·50	·374	3/4	1690	1/2" @ 6"	1/4" @ 8"	37·50	1·54
5"					276	218	182	151	127	108	90	78	69	4·00	·427	3/4	2208	1/2" @ 5½"	1/4" @ 7"	41·67	1·72
5½"					349	276	228	185	155	132	114	99	88	4·50	·480	3/4	2795	1/2" @ 5"	1/4" @ 6"	45·83	1·90
6"					430	340	276	224	191	163	141	122	110	5·00	·534	3/4	3450	1/2" @ 4½"	1/4" @ 5½"	50·00	2·10
6¼"					476	376	304	252	212	180	156	135	122	5·25	·560	3/4	3803	1/2" @ 4¼"	1/4" @ 5"	52·08	2·21
6½"					520	410	332	276	231	195	170	148	133	5·50	·587	3/4	4175	1/2" @ 4"	1/4" @ 5"	54·17	2·30
6¾"					570	448	364	300	252	216	186	163	146	5·75	·614	3/4	4563	5/8" @ 6"	1/4" @ 4½"	56·25	2·48
7"						491	397	329	276	235	204	178	160	6·00	·641	3/4	4968	5/8" @ 5½"	3/8" @ 11"	58·33	2·60
7¼"							430	356	300	256	220	193	172	6·25	·668	3/4	5390	5/8" @ 5¼"	3/8" @ 10"	60·42	2·76
7½"							466	386	324	277	238	207	187	6·50	·694	11/16	5830	5/8" @ 5"	3/8" @ 9½"	62·50	2·92
7¾"							505	416	350	298	257	222	200	6·75	·721	11/16	6283	5/8" @ 5"	3/8" @ 9"	64·58	2·97
8"							540	447	375	320	276	240	216	7·00	·748	11/16	6762	5/8" @ 4½"	3/8" @ 9"	66·67	3·22

Table 4-f.

R.C.C. SLABS

Simply supported slabs (fc—1000, ft—18,000, m—15)

Total Depth of Slab (inches.)	SAFE LOAD (INCLUDING WEIGHT OF SLAB) Lbs/□ Ft. SPAN IN FEET													DETAILS OF SLABS							
	4′	5′	6′	7′	8′	9′	10′	11′	12′	13′	14′	15′	16′	Effective Depth (inches)	Area of Steel/Ft. AT	Cover (inches)	Moment of Resistance Foot Lbs. R.M.	REINFORCEMENT (round bars) Main	REINFORCEMENT (round bars) Distribution	QUANTITIES Per 100 s.ft. Concrete C.ft.	QUANTITIES Per 100 s.ft. Steel Cwt.
3"		313	217	160	122	96	78	65	54					2·25	·340	1/2	976	1/2" @ 7"	1/4" 12"	25·00	1·30
3½"			325	238	182	144	117	97	81	69	60			2·75	·415	1/2	1460	1/2" @ 5½"	,, 12"	29·17	1·60
4"			387	284	218	172	139	115	97	82	71	62		3·00	·452	3/4	1740	,, 5"	,, 12"	33·33	1·74
4½"				385	295	233	189	156	131	112	96	84	74	3·50	·528	1/2	2300	,, @ 4½"	,, 10"	37·50	1·96
5"				503	385	304	246	204	171	146	126	110	96	4·00	·604	11/16	3080	5/8" @ 6"	,, 10"	41·67	2·26
5½"					489	386	313	258	217	185	160	139	122	4·50	·680	11/16	3910	,, @ 5½"	,, 9"	45·83	2·45
6"						476	386	319	268	228	197	171	150	5·00	·755	5/8	4820	3/4" @ 7"	,, 9"	50·00	2·77
6¼"						525	425	351	296	252	217	189	166	5·25	·793	5/8	5310	,, @ 7"	,, 9"	52·08	2·77
6½"						577	467	386	324	276	238	208	183	5·50	·830	5/8	5840	,, @ 6"	,, 7"	54·17	3·26
6¾"							510	422	355	302	261	227	200	5·75	·868	5/8	6380	,, @ 6"	,, 7"	56·25	3·26
7"							555	458	385	328	283	247	217	6·00	·906	11/16	6940	5/8" @ 4"	,, 7"	58·33	3·38
7¼"							603	498	419	357	308	268	235	6·25	·945	5/8	7530	3/4" @ 5½"	,, 6"	60·42	3·57
7½"								540	452	386	332	290	254	6·50	·981	5/8	8150	,, @ 5"	,, 6"	62·50	3·90
7¾"								581	489	416	359	313	274	6·75	1·020	5/8	8780	,, @ 5"	,, 6"	64·58	3·90
8"									525	447	386	335	296	7·00	1·060	5/8	9450	,, @ 5"	,, 6"	66·67	3·90

Table 4-g.
R.C.C. SLABS (continuous)
(fc—750, ft.—18,000, m—15)

SEMI CONTINUOUS $\left(\frac{WL}{10}\right)$ — SAFE LOAD (INCLUDING WEIGHT OF SLAB) Lbs./□ Ft. SPAN IN FEET

Total Depth. of Slab (Inches)	4'	5'	6'	7'	8'	9'	10'	11'	12'	13'	14'	15'	16'
3"		255	177	130	100	79	64	52					
3½"			262	194	149	117	95	79	66	56			
4"			370	271	209	166	132	109	92	79			
4½"			429	316	242	191	155	129	107	91	79		
5"					315	245	201	170	140	120	102		
5½"					400	312	255	210	177	150	127	112	100
6"					492	387	315	260	220	187	161	140	122
6¼"					544	431	350	287	244	207	179	159	135
6½"					597	470	381	320	265	225	194	170	149
6¾"					650	512	417	344	290	245	212	185	162
7"						560	454	375	314	267	231	201	179
7¼"						612	495	406	344	292	250	219	192
7½"						656	532	437	369	315	271	236	207
7¾"						712	575	475	400	337	294	254	225
8"						762	617	509	427	365	312	274	242

FULLY CONTINUOUS $\left(\frac{WL}{12}\right)$ — SAFE LOAD (INCLUDING WEIGHT OF SLAB) Lbs./□ Ft. SPAN IN FEET

Total Depth. of Slab (Inches)	4'	5'	6'	7'	8'	9'	10'	11'	12'	13'	14'	15'	16'
3"		306	213	156	120	94	75	63					
3½"			315	232	178	141	114	94	79	67			
4"			444	325	250	199	159	130	111	94			
4½"			514	379	291	229	186	154	129	109	94		
5"					378	294	241	204	168	144	123		
5½"					480	375	306	252	213	180	153	135	120
6"					591	465	378	312	264	225	193	168	147
6¼"					652	517	420	345	292	249	214	190	162
6½"					717	564	457	384	318	270	232	204	178
6¾"					780	615	451	412	348	294	255	222	195
7"						672	544	450	375	321	277	241	214
7¼"						735	594	487	412	351	300	262	231
7½"						787	639	525	442	378	325	288	249
7¾"						855	690	570	480	405	352	304	270
8"						915	741	610	513	338	375	328	291

Table 4-h.

R.C.C. SLABS (continuous)

(fc—600, ft.—16,000, m—15)

SEMI CONTINUOUS $\left(\frac{WL}{10}\right)$

Total Depth of Slab (Inches)	SAFE LOAD (INCLUDING WEIGHT OF SLAB) Lbs/□ Ft. SPAN IN FEET												
	4'	5'	6'	7'	8'	9'	10'	11'	12'	13'	14'	15'	16'
3"	297	190	132	97	75	59							
3½"		297	197	145	111	87	71						
4"		397	276	202	155	122	100	82					
4½"		465	322	237	181	144	116	95					
5"		605	420	310	236	186	151	125	105	90			
5½"				390	299	236	191	157	132	112	97		
6"				481	369	291	236	195	164	140	120	102	
6¼"				531	406	321	260	215	180	152	132	116	101
6½"				587	449	355	287	237	200	171	147	127	112
6¾"				635	486	384	311	256	216	184	159	137	121
7"				696	534	421	342	282	237	201	174	151	134
7¼"				752	575	455	369	305	255	217	187	165	145
7½"				819	625	495	401	332	279	237	205	177	156
7¾"				877	672	531	430	355	299	251	219	192	169
8"						575	455	384	324	275	227	206	181

FULLY CONTINUOUS $\left(\frac{WL}{12}\right)$

Total Depth of Slab (Inches)	SAFE LOAD (INCLUDING WEIGHT OF SLABS) Lbs./□ Ft. SPAN IN FEET												
	4'	5'	6'	7'	8'	9'	10'	11'	12'	13'	14'	15'	16'
3"	357	228	159	117	90	70							
3½"		357	237	174	133	105	85						
4"		477	331	243	186	147	120	99					
4½"		558	387	285	217	172	139	114					
5"		726	504	372	283	223	181	150	126	108			
5½"				468	358	283	229	179	159	135	117		
6"				577	442	349	283	234	196	168	144	123	
6¼"				637	487	385	312	258	216	183	159	139	121
6½"				705	538	425	345	285	240	205	177	153	135
6¾"				762	583	460	373	307	259	220	180	165	145
7"				835	640	505	411	339	285	241	208	181	160
7¼"				903	690	546	442	366	306	261	225	198	174
7½"				982	750	594	481	399	334	285	246	213	187
7¾"				1053	807	637	516	426	357	303	262	231	202
8"						690	558	460	388	330	285	247	217

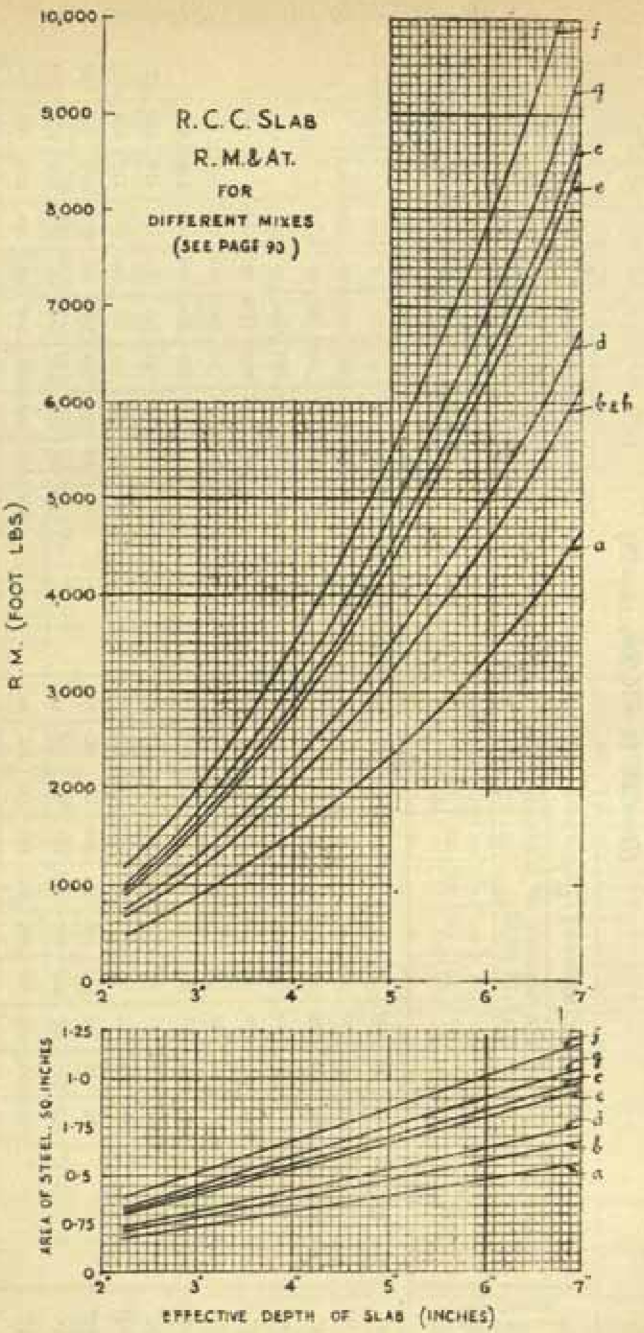

R.C.C. SLAB
R.M.& AT.
FOR
DIFFERENT MIXES
(SEE PAGE 93)
R.M. (FOOT LBS)
10,000
9,000
8,000
7,000
6,000
5,000
4,000
3,000
2000
1000
0
2"
3"
4"
5"
6"
7"
j
g
c
e
d
b & h
a
AREA OF STEEL SQ. INCHES
1·25
1·0
1·75
0·5
0·75
0
EFFECTIVE DEPTH OF SLAB (INCHES)

Chart 4·8.

DESIGN OF R.C.C FLOOR SLABS

STRESSES: $fc = 600$, $ft = 16{,}000$ & $m = 15$

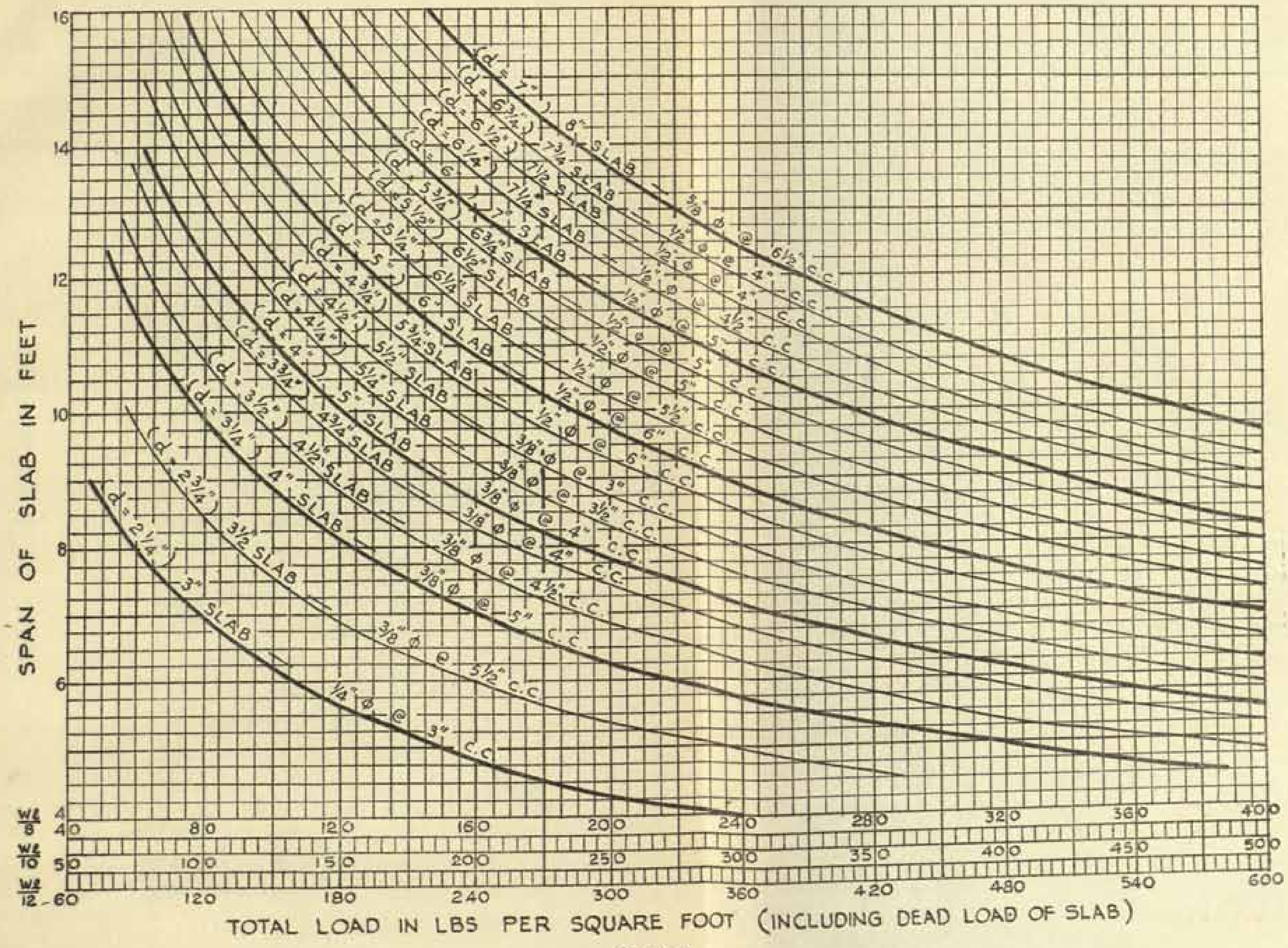


Chart 4-9.

DESIGN OF R.C.C. FLOOR SLAB

STRESSES : C = 750 . T = 18,000 & m = 15

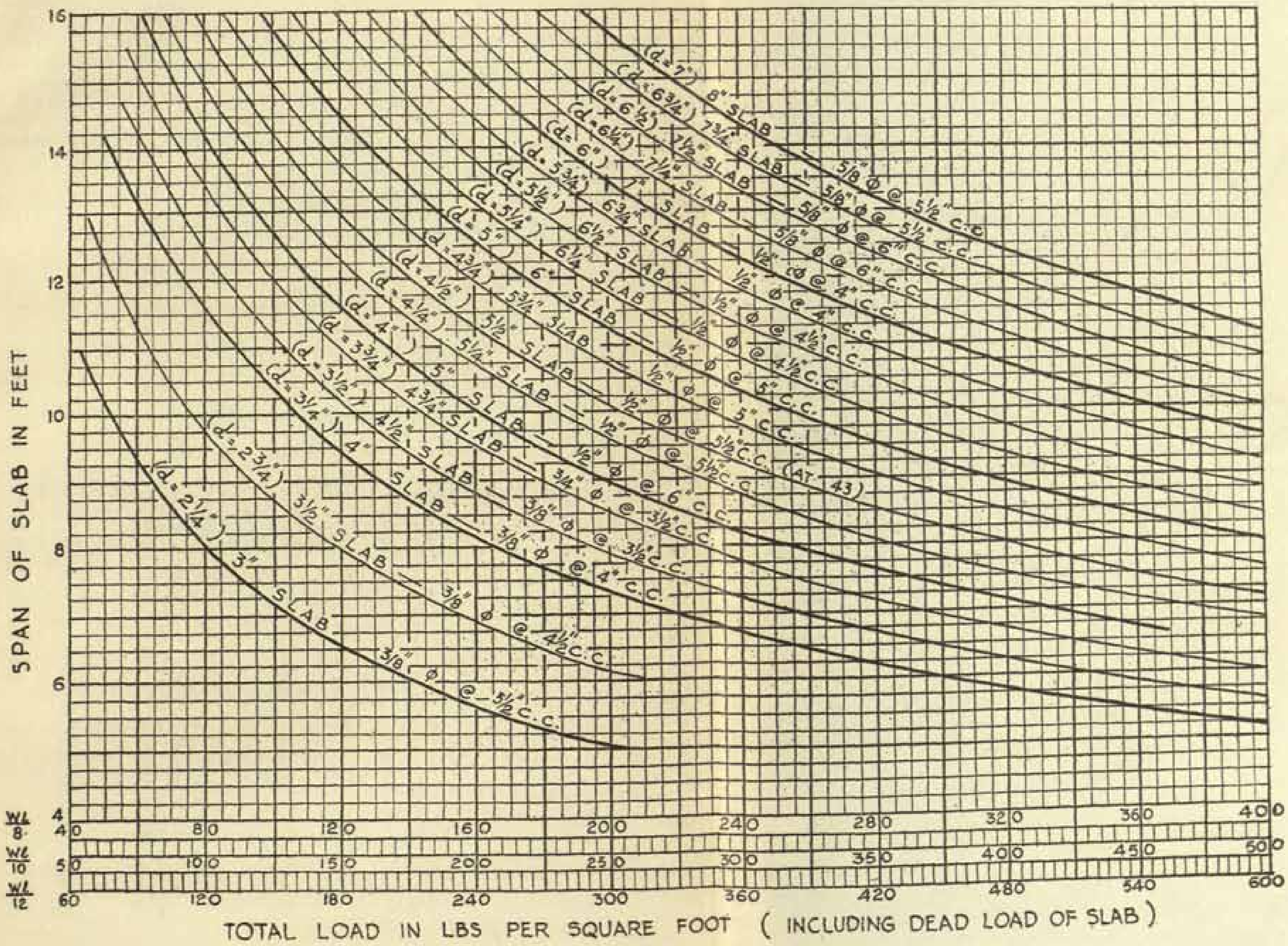


Chart 4·10.

DESIGN OF R.C.C. FLOOR SLAB

STRESSES – $f_c = 750$. $f_t = 18{,}000$ & $m = 18$.

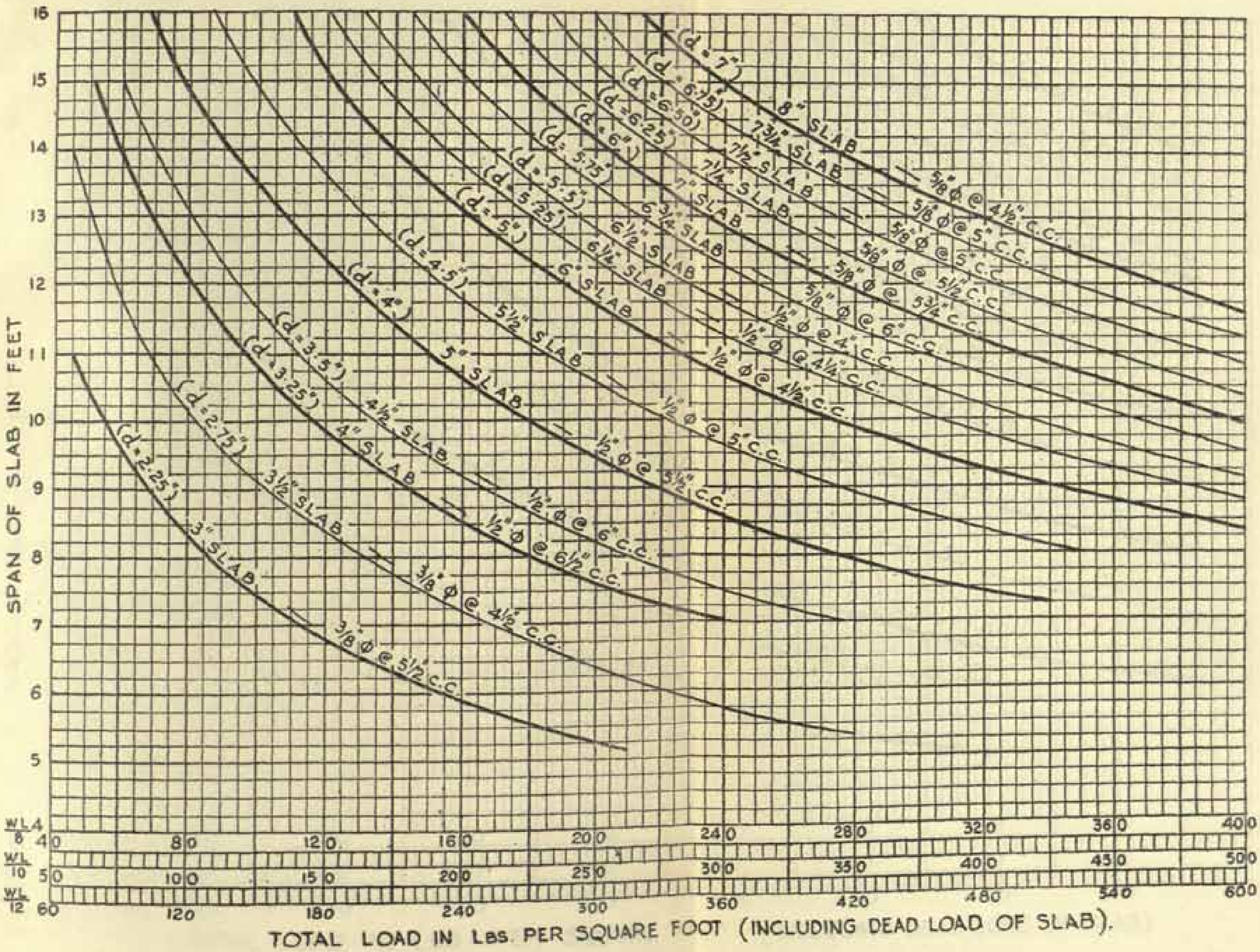


Chart 4-11.

4.3 EXAMPLES ILLUSTRATING USE OF VARIOUS CHARTS AND TABLES IN THIS CHAPTER.

(1) Charts 4-1 & 4-2 and Table 4-a:

Find R.M. & At of a slab where stresses to be adopted are:

fc = 550 lbs per sq. inch
ft = 16000 " " " "
m = 15
ft/fc = 16000/550 = 29.
∴ n = .34 from chart 4-1.
∴ j = 1 — n/3 = .867
∴ R.M. = ½fc × n × jbd² = 550/2 × .34 × .87bd²
= 83bd²
& At (from chart 4-2) = .6%

The same values can be obtained directly from table 4-a.

(2) Charts 4-3 to 4-7:

Find R.M. of a slab, effective depth 5″ and reinforced with,

(a) .3 sq. inches of steel (5/16″ @ 3″ c.c.)
(b) .6 —do.— (7/16″ @ 3½″ c.c.)
and designed for fc = 750 psi, ft = 18000 psi & m = 18.

Case a	*Case b*
p = .3 × 100/60 = .5%	p = .6 × 100/60 = 1.0%
n (chart 4.3) = .342	.445
j = 1 — .343/3 = .885	1 — .445/3 = .852
R.M = At × ft × jd	fc/2 × n × j × bd²
.3 × 18000 × 885 × 5 in. lbs.	750/2 × .445 × .852 × 12 × 5²
= 1950 ft. lbs.	3500 ft. lbs.

or (from chart 4-4)

Case a	*Case b*
Q = 77 bd²	Q = 142 bd²
= 77 × 25	= 142 × 25
= 1925 ft. lbs.	= 3550 ft. lbs.

or Direct from chart 4-7

Case a	*Case b*
1925 ft. lbs.	3550 ft. lbs.

Chart 4-8 or Table 4-b.

Find R.M. & At for a slab (effective depth 6") designed as per B.S. Code with aggregates as per B.S. 882.

Refer table 4-b under "g"	R.M.=6948 ft. lbs & At=.907
Refer chart No. 4-8	R.M.=6950 " " At=.900

Tables 4-c, 4-d, 4-e, etc. and

Charts 4-9, 4-10, 4-11 & 4-12.

are self explanatory giving

(a) safe load per sq. ft.

(b) other structural particulars

(c) quantities of steel and concrete per 100 s. ft.

for simply supported slabs designed for various values of fc, ft & m. For continuous and semi-continuous spans the safe loads may be increased by 50% and 20% respectively.

CHAPTER 5.

RECTANGULAR BEAMS

CONTENTS

CHAPTER 5

RECTANGULAR BEAMS

5.1 SINGLY REINFORCED.

The same formulæ as those for slabs apply to design of rectangular beams. However, in case of slabs, the concrete area is generally sufficient to meet the shear stresses, while in case of rectangular beams provision for shear stresses will have to be made by means of bent up bars and stirrups.

The charts and tables in this chapter are useful in designing rectangular beams ordinarily employed in practice. Continuous beams in a structure which are treated as T-beams in centre of span, behave as rectangular beams over supports and the charts can be used for their calculation by placing the required reinforcement at top.

Tables 5-a, 5-b and 5-c give M.R. & A_T for rectangular beams for different concrete and steel stresses.

Charts 5-1, 5-2 and 5-3 also give M.R. & A_T as above.

Tables 5-d, and 5-e give safe load per r.ft. for rectangular beams as above.

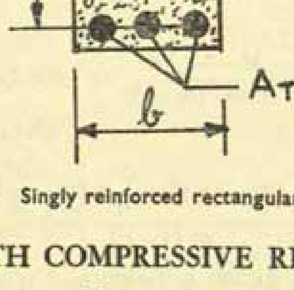


Fig. 5-1. Singly reinforced rectangular beams.

5.2 BEAMS WITH COMPRESSIVE REINFORCEMENT.

In practice, beams with compression steel have to be used in the following cases:

(a) T-beams, when continuous, behave as rectangular beams on support and when singly reinforced require considerable depth to take up the B.M. Steel for compression being automatically available from the two spans adjacent to a support, a doubly reinforced rectangular beam is more suitable from architectural considerations and practical reasons.

(b) Rectangular beams, lintels, etc. where the depth is necessarily restricted from consideration of headway or other architectural reasons.

(c) Braces, walls of storage reservoirs, etc. where B.M. reverses according to loading conditions.

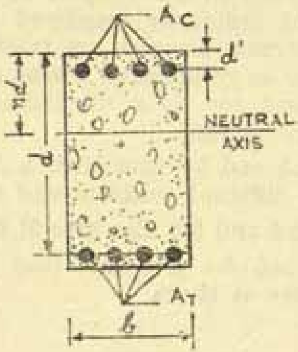


Fig. 5-2. Beam with compression reinforcement.

In case of (a) and (c), the following formulæ give the amount of Ac and AT in sq. inches for B.M.=M inch lbs.

$$A_c = \frac{M - 95\ bd^2}{K_1 d} \quad \text{or} \quad \frac{M - 126\ bd^2}{K_2 d}$$

$$A_T = .00675\ bd + \frac{M - 95\ bd^2}{16000\ (d - d^1)} \quad \text{or} \quad .008\ bd + \frac{M - 126\ bd^2}{18000\ (d - d^1)}$$

(Old L.C.C.) (New L.C.C.R.)

$$\text{where } K_1 \text{ or } K_2 = \frac{fs\ (m-1)\ (1 - \frac{d^1}{d})\ (n - \frac{d^1}{d})}{m\ (1-n)}$$

the values of fs being 16000 & 18000 and n being .36 & .385 in case of Old and New L.C.C.R. respectively and m=15. For both cases, the values of K_1 and K_2 are tabulated below:—

d^1/d	.02	.04	.06	.08	.10	.12	.14	.16	.18	.20
K_1	7780	7150	6570	5980	5450	4920	4410	3920	3440	2980
K_2	9620	9000	8280	7680	6960	6360	5760	5160	4560	4080

In case of (c), it is necessary to provide equal top and bottom steel. In this case, both steel and concrete may not be stressed to the maximum permitted stress. If steel is assumed to be stressed to the maximum permissible limit, the stress in concrete will be below the maximum limit. Alternatively if concrete is fully stressed, steel will be understressed. The following procedure is necessary to find out the R.M. of section reinforced with known amount of Ac and AT:—

Determine position of neutral axis by the general formula

$$n=\sqrt{[mr+(m-1)r^1]^2+2\,[mr+(m-1)r^1\frac{d^1}{d}}$$

$$-[mr+(m-1)r^1]$$

where $r=\frac{At}{bd}$ and $r^1=\frac{Ac}{bd}$

After the position of neutral axis is determined, the R.M. can be found by the following formulæ:—

$$\frac{M}{bd^2}=fs\,\frac{n}{m(1-n)}\left[\frac{n}{2}\left(1-\frac{n}{3}\right)+\frac{Ac}{bd}\left(1-\frac{d^1}{d}\right)\left(n-\frac{d^1}{d}\right)\frac{m-1}{n}\right]=Q$$

or

$$\frac{M}{bd^2}=\frac{fc}{2}\,n\left(1-\frac{n}{3}\right)+\frac{Ac}{bd}\left(1-\frac{d^1}{d}\right)\left(n-\frac{d^1}{d}\right)\frac{(m-1)}{n}\,fc=Q$$

The smaller of the two values of Q calculated by the above formulæ to be adopted. The values of Q are given below for a few typical cases.

m=15

	Max. permissible stressses $fc=600$ lbs. p.s.i. $fs=16000$ lbs. p.s.i.	Max. permissible stresses $fc=750$ p.s.i. $fs=18000$ p.s.i.
Ac=AT=1%	141	159
1.5%	186	232
2%	221	276

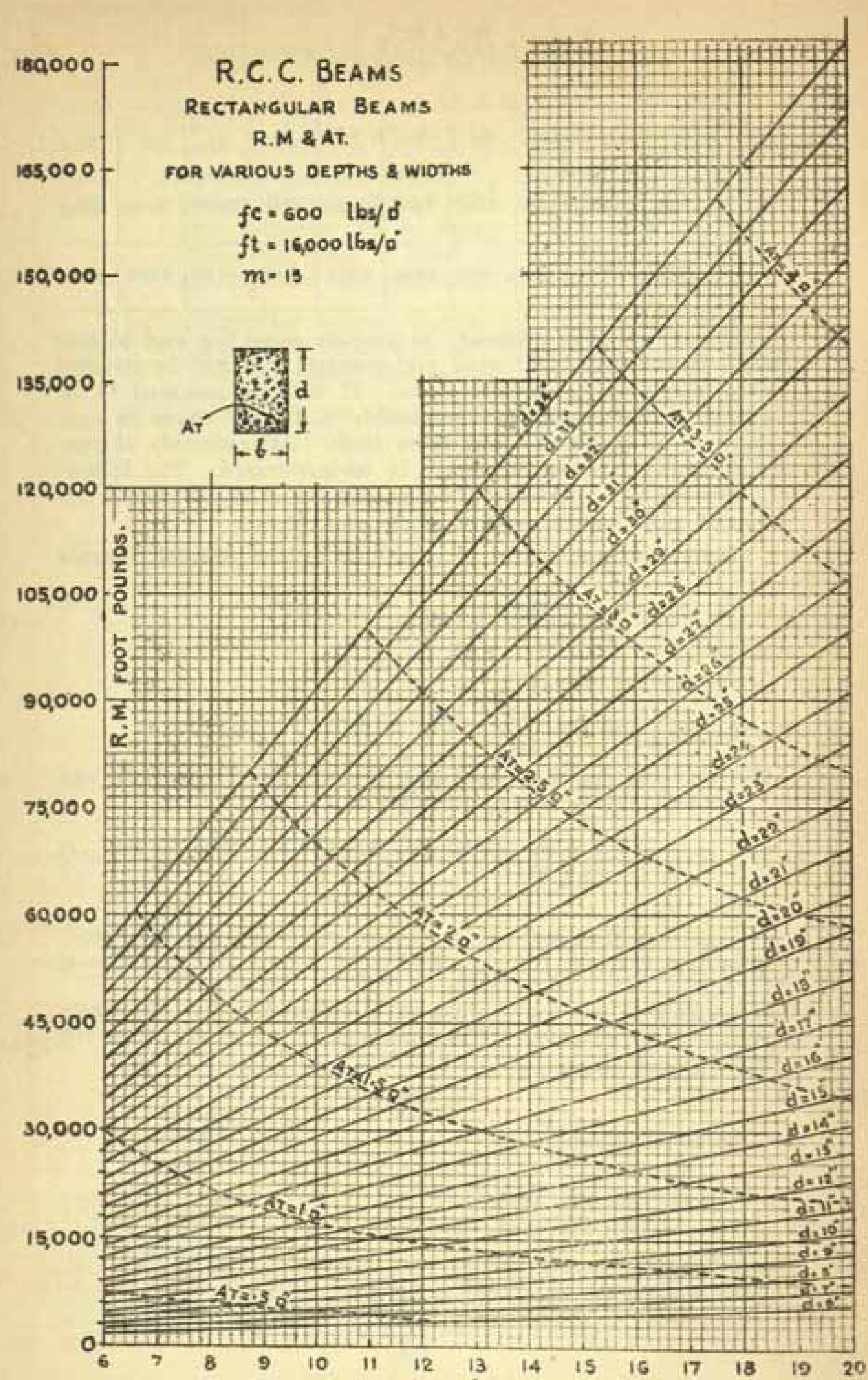

R.C.C. BEAMS
RECTANGULAR BEAMS
R.M & AT.
FOR VARIOUS DEPTHS & WIDTHS
fc = 600 lbs/□"
ft = 16,000 lbs/□"
m = 15
R.M. FOOT POUNDS.
BREADTH "b" INCHES

Chart 5-1.

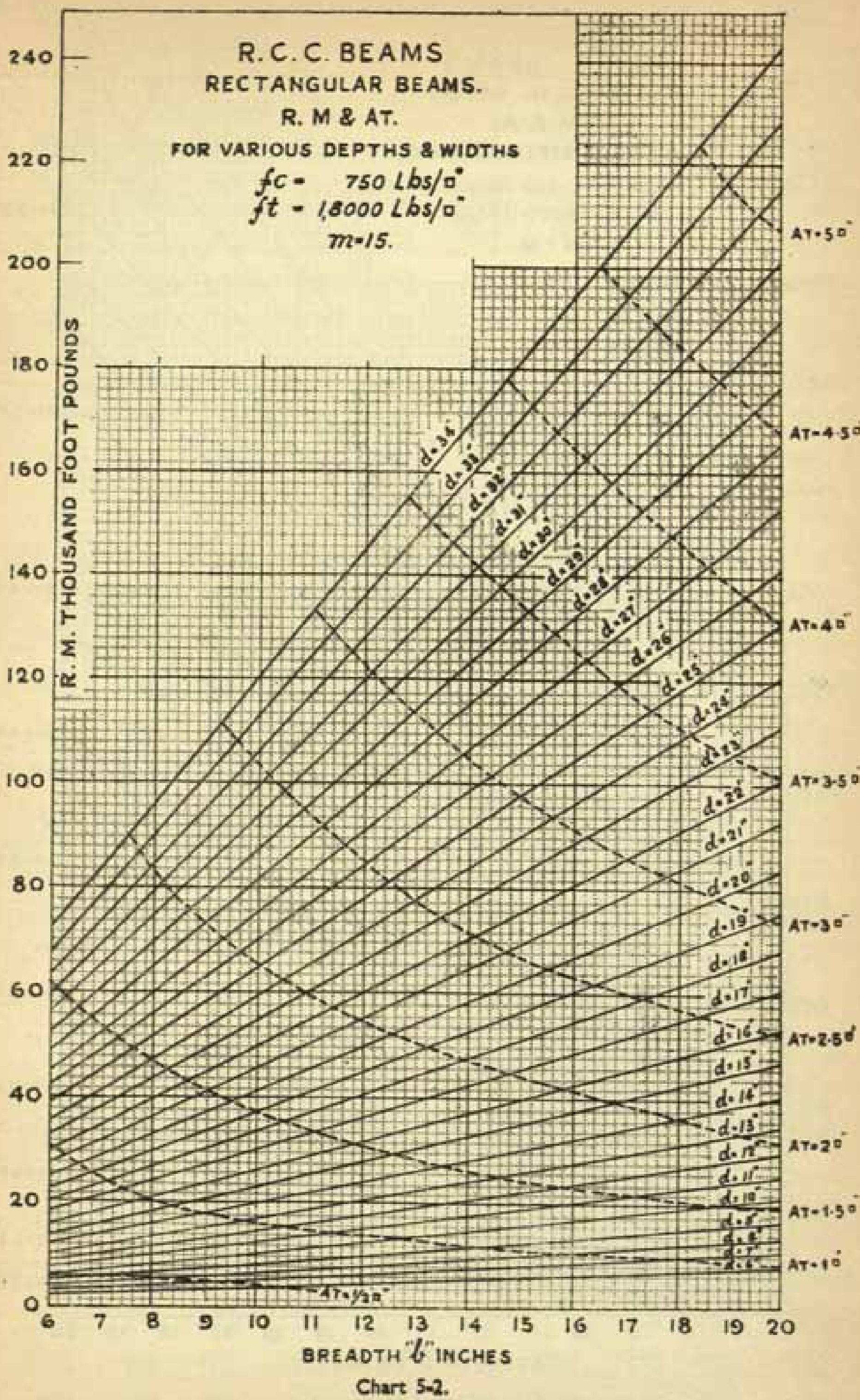

R.C.C. BEAMS
RECTANGULAR BEAMS.
R. M & AT.
FOR VARIOUS DEPTHS & WIDTHS
fc = 750 Lbs/□"
ft = 18000 Lbs/□"
m=15.
R. M. THOUSAND FOOT POUNDS
BREADTH "b" INCHES
AT=5□"
AT=4.5□"
AT=4□"
AT=3.5□"
AT=3□"
AT=2.5□"
AT=2□"
AT=1.5□"
AT=1□"
AT=½□"

Chart 5-2.

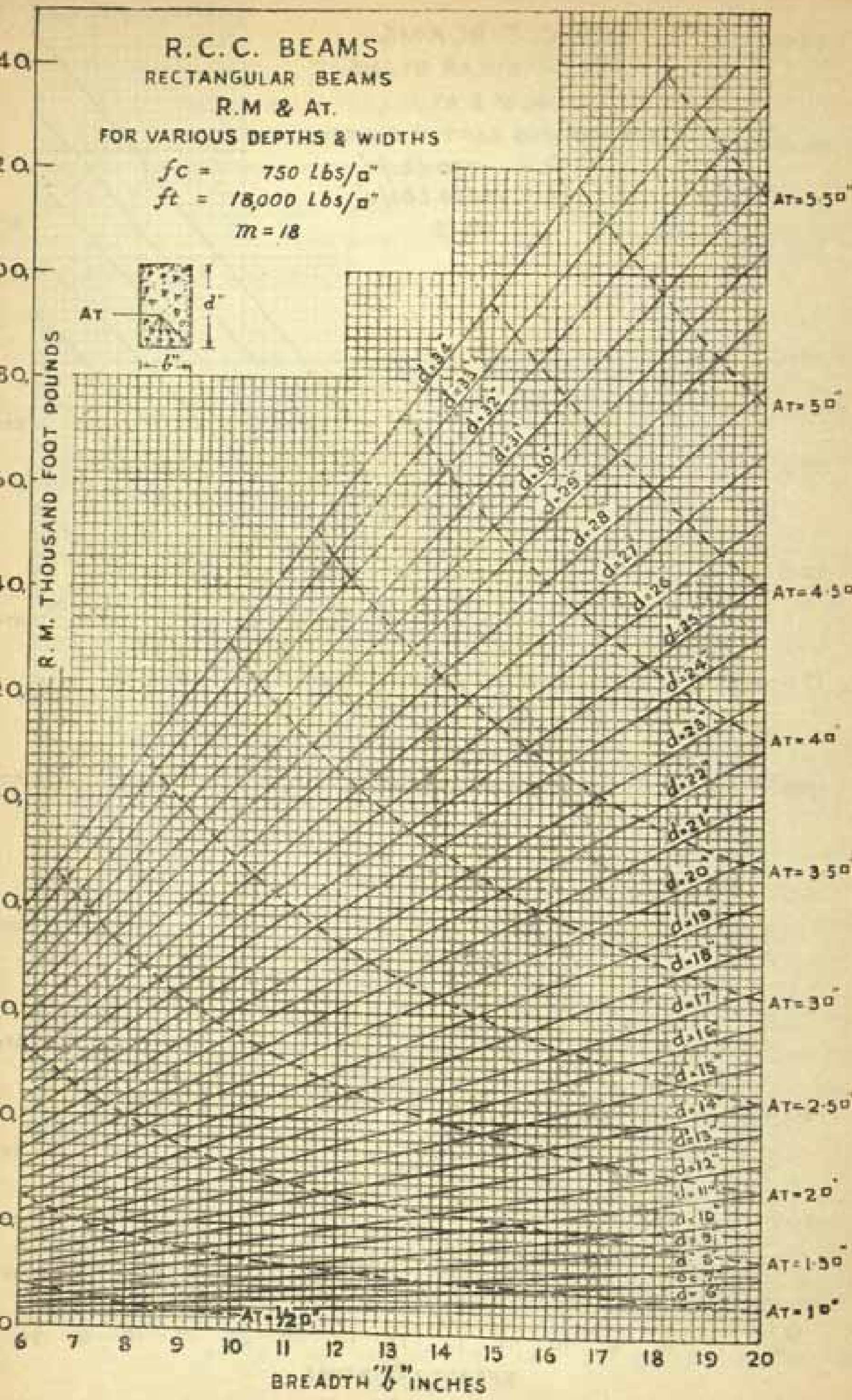

R.C.C. BEAMS
RECTANGULAR BEAMS
R.M & AT.
FOR VARIOUS DEPTHS & WIDTHS
fc = 750 lbs/□"
ft = 18,000 lbs/□"
m = 18
AT
d"
b"
R. M. THOUSAND FOOT POUNDS
240
220
200
180
160
140
120
100
80
60
40
20
0
6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
BREADTH "b" INCHES
AT=5.5□"
AT=5□"
AT=4.5□"
AT=4□"
AT=3.5□"
AT=3□"
AT=2.5□"
AT=2□"
AT=1.5□"
AT=1□"
AT=1/2□"

Chart 5-3.

Table 5-a. **RECTANGULAR BEAMS R.M. & At** for various depths & widths.

fc = 600 ft = 16000 m = 15. R.M. in ft.lbs.

d \ b	6″	8″	9″	10″	12″	14″	15″	16″	18″	20″
6″	1710 ·243	2280 ·322	2565 ·36	2850 ·41	3420 ·49	3990 ·57	4275 ·61	4560 ·65	5130 ·73	5700 ·81
7″	2327 ·28	3103 ·38	3491 ·42	3879 ·47	4655 ·56	5431 ·66	5819 ·71	6207 ·76	6982 ·85	7758 ·94
8″	3040 ·32	4053 ·44	4560 ·49	5070 ·54	6086 ·66	7093 ·76	7600 ·81	8107 ·86	9120 ·97	10133 1·08
9″	3847 ·36	5130 ·49	5771 ·55	6412 ·61	7695 ·73	8977 ·85	9619 ·91	10260 ·97	11542 1·09	12838 1·21
10″	4750 ·40	6333 ·54	7125 ·61	7916 ·68	9500 ·80	11083 ·95	11875 1·0	12667 1·08	14250 1·20	15833 1·35
11″	5747 ·44	7665 ·60	8621 ·67	9579 ·75	11495 ·88	13411 1·02	14379 1·1	15327 1·19	17242 1·33	19158 1·48
12″	6840 ·48	9120 ·65	10260 ·73	11400 ·82	13680 ·96	15960 1·13	17100 1·2	18240 1·30	20520 1·44	22800 1·62
13″	8027 ·52	10703 ·71	12041 ·79	13379 ·89	16055 1·06	18731 1·22	20069 1·31	21407 1·41	24083 1·56	26758 1·75
14″	9310 ·56	12413 ·76	13965 ·85	14717 ·94	18620 1·12	21723 1·32	23275 1·41	24827 1·51	27930 1·68	31033 1·89
15″	10687 ·60	14250 ·82	16031 ·91	17812 1·03	21375 1·20	24937 1·41	26719 1·51	28500 1·62	32062 1·81	35625 2·02
16″	12160 ·64	16213 ·87	18240 ·97	20266 1·08	24320 1·28	28373 1·50	30400 1·61	32427 1·73	36840 1·93	40533 2·16
17″	13727 ·68	18303 ·93	20591 1·03	22879 1·15	27455 1·36	32031 1·60	34319 1·71	36607 1·83	41162 2·05	45758 2·29
18″	15390 ·72	20520 ·98	23085 1·09	25650 1·21	30780 1·54	35910 1·70	38475 1·81	41040 1·94	46170 2·17	51300 2·42
19″	17147 ·78	22863 1·04	25721 1·15	28579 1·28	34295 1·56	40011 1·79	42868 1·91	45727 2·05	51460 2·30	57158 2·56
20″	19000 ·82	25333 1·09	28500 1·21	31667 1·35	38000 1·64	44333 1·88	47500 2·02	50666 2·16	57000 2·40	63333 2·70
21″	20947 ·86	27930 1·15	31421 1·27	34912 1·42	41878 1·72	48877 1·98	52369 2·12	55860 2·27	62845 2·52	69825 2·82
22″	22990 ·90	30653 1·20	34485 1·33	38317 1·49	45980 1·80	53643 2·07	57475 2·22	61307 2·38	68970 2·65	76633 2·96
23″	25127 ·94	33503 1·26	37691 1·39	41880 1·56	50255 1·88	58631 2·17	62818 2·32	67004 2·49	75382 2·77	83758 3·10
24″	27360 ·98	36480 1·31	41040 1·45	45600 1·63	54720 1·96	63840 2·26	68400 2·42	72960 2·59	82080 2·89	91200 3·22
25″	29687 1·02	39583 1·36	41198 1·51	49479 1·69	59375 2·04	69271 2·35	74219 2·52	79166 2·70	89062 3·0	98958 3·36
26″	32110 1·06	42813 1·42	48165 1·57	53516 1·75	64220 2·12	74923 2·45	80292 2·63	85627 2·81	96330 3·12	107033 3·50
27″	34627 1·10	46170 1·47	51941 1·63	57712 1·82	69255 2·20	80797 2·54	86569 2·72	92340 2·92	103882 3·25	115425 3·64
28″	37240 1·14	49653 1·53	55860 1·69	62066 1·88	74480 2·28	86893 2·64	93100 2·83	99317 3·02	111720 3·37	124133 3·76
29″	39947 1·20	53263 1·58	59921 1·75	66579 1·96	79895 2·40	93211 2·73	99864 2·92	106526 3·13	119842 3·48	133158 3·90
30″	42750 1·24	57066 1·64	64125 1·82	71250 2·02	85500 2·48	99750 2·82	106875 3·03	114000 3·23	128250 3·61	142500 4·05
31″	45687 1·28	60863 1·69	68471 1·88	76079 2·10	91295 2·56	106511 2·92	114119 3·12	121727 3·34	136942 3·73	152158 4·18
32″	48640 1·32	64853 1·73	72960 1·96	81067 2·17	97280 2·64	113493 3·00	121600 3·22	129707 3·45	145920 3·85	162133 4·30
33″	51727 1·36	68970 1·78	77591 2·02	86212 2·23	103455 2·72	120699 3·10	129319 3·32	137940 3·56	155182 3·98	172425 4·45
34″	54910 1·40	73213 1·84	82365 2·08	91517 2·30	109820 2·80	128123 3·20	137250 3·43	146427 3·67	164730 4·10	183033 4·58

Table 5-b. RECTANGULAR BEAMS R.M. & A_T for various depths & widths

$f_c = 750 \quad f_t = 18000 \quad m = 15.$ R.M. in ft.lbs.

d \ b	6"	8"	9"	10"	12"	14"	15"	16"	18"	20"
6"	2268 ·288	3024 ·384	3402 ·432	3780 ·480	4536 ·576	5292 ·67	5670 ·72	6048 ·77	6804 ·86	7560 ·96
7"	3087 ·336	4116 ·448	4630 ·504	5145 ·560	6174 ·672	7203 ·78	7717 ·84	8232 ·90	9261 1·01	10290 1·12
8"	4032 ·384	5376 ·512	6048 ·576	6720 ·640	8064 ·768	9408 ·90	10080 ·96	10752 1·02	12096 1·15	13440 1·28
9"	5103 ·432	6804 ·576	7654 ·648	8505 ·720	10206 ·864	11907 1·01	12757 1·08	13608 1·15	15309 1·30	17010 1·44
10"	6300 ·480	8400 ·640	9450 ·720	10500 ·800	12600 ·960	14700 1·12	15750 1·20	16800 1·28	18900 1·44	21000 1·60
11"	7623 ·528	10164 ·704	11434 ·792	12705 ·880	15286 1·056	15187 1·23	19057 1·32	20328 1·41	22869 1·58	25410 1·76
12"	9072 ·576	12096 ·768	13608 ·864	15120 ·960	18144 1·152	21168 1·34	22680 1·44	24192 1·54	27216 1·73	30240 1·92
13"	10647 ·624	14196 ·832	15970 ·936	17745 1·040	21294 1·248	24843 1·46	26617 1·56	28392 1·66	31941 1·87	35490 2·08
14"	12348 ·672	16464 ·896	18522 1·00	20580 1·12	24696 1·34	28812 1·57	30870 1·68	32928 1·79	37044 2·02	41160 2·24
15"	14175 ·72	18900 ·96	21262 1·08	23625 1·20	28350 1·44	33075 1·68	35437 1·80	37800 1·92	42525 2·16	47250 2·40
16"	16128 ·77	21506 1·02	24192 1·15	26880 1·28	32256 1·54	37632 1·79	40320 1·92	43008 2·05	48384 2·30	53760 2·56
17"	18207 ·82	24276 1·09	27310 1·22	30345 1·36	36414 1·63	42483 1·90	45517 2·04	48552 2·18	54621 2·45	60690 2·72
18"	20402 ·86	27216 1·15	30618 1·30	34020 1·44	40824 1·73	47628 2·02	51030 2·16	54432 2·3	61236 2·59	68040 2·88
19"	22743 ·91	30324 1·22	34114 1·37	37905 1·52	45486 1·82	53067 2·13	56857 2·28	60648 2·43	68229 2·74	75810 3·04
20"	25200 ·96	33600 1·28	37800 1·44	42000 1·60	50400 1·92	58800 2·24	63000 2·40	67200 2·56	75600 2·88	84000 3·20
21"	27783 1·01	37044 1·34	41674 1·51	46305 1·68	55566 2·02	64827 2·35	69457 2·52	74088 2·69	83349 3·02	92610 3·36
22"	30492 1·056	40656 1·41	45738 1·58	50820 1·76	60984 2·11	71148 2·46	76230 2·64	81312 2·82	91476 3·17	101640 3·52
23"	33327 1·10	44436 1·47	49990 1·66	55542 1·84	66654 2·21	77763 2·58	83317 2·76	88872 2·94	99981 3·31	111090 3·68
24"	36288 1·15	48384 1·54	54432 1·73	60480 1·92	72576 2·3	84672 2·69	90720 2·88	96768 3·07	108864 3·46	120960 3·84
25"	39375 1·20	52500 1·60	59062 1·80	65625 2·00	78750 2·40	91875 2·8	98437 3·00	105000 3·20	118125 3·60	131250 4·00
26"	42588 1·24	56784 1·67	63882 1·87	70980 2·08	85176 2·50	99372 2·91	106470 3·12	113568 3·33	127764 3·74	141960 4·16
27"	45927 1·30	61236 1·73	68890 1·94	76545 2·16	91854 2·59	107163 3·02	114817 3·24	122472 3·46	137781 3·89	153090 4·32
28"	49392 1·34	65856 1·79	74088 2·02	82320 2·24	98784 2·67	115248 3·14	123480 3·36	131712 3·58	148176 4·03	164640 4·48
29"	52983 1·39	70644 1·86	79474 2·09	88305 2·32	105966 2·78	123627 3·25	132457 3·48	141288 3·71	158949 4·18	176610 4·64
30"	56700 1·44	75600 1·92	85050 2·16	94500 2·40	113400 2·88	132300 3·36	141750 3·60	151200 3·84	170100 4·32	189000 4·80
31"	60543 1·49	80724 1·98	90814 2·23	100905 2·48	121086 2·98	141267 3·47	151357 3·73	161448 3·97	181629 4·46	200810 4·96
32"	64512 1·54	86016 2·05	96768 2·30	107520 2·56	129024 3·07	150528 3·58	161280 3·84	172032 4·10	193536 4·61	215040 5·12
33"	68603 1·58	91476 2·11	102910 2·38	114345 2·64	137214 3·17	160083 3·70	171570 3·96	182952 4·22	205821 4·75	228690 5·28
34"	72828 1·63	97104 2·18	109242 2·45	121380 2·72	145656 3·26	169932 3·81	182070 4·08	194208 4·35	218484 4·90	242760 5·44

Table 5-c. RECTANGULAR BEAMS R.M. & A_T for various depths & widths.

$f_c = 750$ $f_t = 18000$ & $m = 18$. R.M. in ft.lbs.

d \ b	6"	8"	9"	10"	12"	14"	15"	16"	18"	20"
6"	2466 ·32	3287 ·43	3699 ·481	4127 ·53	4932 ·64	5743 ·75	6165 ·80	6575 ·85	7398 ·96	8254 1·07
7"	3356 ·37	4475 ·50	5034 ·56	5618 ·62	6713 ·75	7831 ·87	8391 ·94	8950 1·00	10069 1·12	11230 1·25
8"	4384 ·43	5845 ·57	6576 ·64	7338 ·71	8768 ·85	10229 1·00	10960 1·07	11690 1·14	13152 1·28	14613 1·42
9"	5548 ·48	7397 ·64	8322 ·72	9287 ·80	11097 ·96	12946 1·12	13871 1·20	14795 1·28	16645 1·44	18474 1·60
10"	6850 ·53	9133 ·71	10275 ·80	11466 ·89	13700 1·07	15983 1·25	17125 1·34	18266 1·42	20550 1·60	22833 1·78
11"	8288 ·59	11050 ·78	12432 ·88	13873 ·98	16577 1·18	19337 1·37	20721 1·47	22101 1·57	24865 1·76	27627 1·96
12"	9864 ·64	13151 ·85	14796 ·96	16511 1·07	19728 1·28	23015 1·50	24660 1·60	26303 1·71	29592 1·92	32879 2·14
13"	11576 ·69	15434 ·93	17364 1·04	19377 1·16	23153 1·39	27011 1·62	28941 1·74	30869 1·85	34729 2·08	38587 2·31
14"	13426 ·75	17900 1·00	20139 1·12	22473 1·25	26852 1·50	31326 1·74	33565 1·87	35801 2·00	40278 2·24	44752 2·49
15"	15412 ·80	20549 1·07	23118 1·20	25798 1·34	30825 1·60	35961 1·87	38531 2·00	41098 2·14	46237 2·40	51374 2·67
16"	17536 ·85	23380 1·14	26304 1·28	29352 1·42	35072 1·71	40916 1·99	43840 2·14	46760 2·28	52608 2·56	58452 2·85
17"	19796 ·91	26394 1·21	29694 1·36	33136 1·51	39593 1·82	46190 2·12	49391 2·27	52788 2·42	59389 2·72	66260 3·03
18"	22194 ·96	29590 1·28	33291 1·41	37149 1·60	44388 1·92	51784 2·24	55485 2·40	59181 2·56	66485 2·88	74298 3·20
19"	24728 1·02	32970 1·35	37092 1·52	41302 1·69	49457 2·03	57698 2·37	61821 2·54	65990 2·71	74077 3·04	82784 3·38
20"	27400 1·07	36532 1·42	41100 1·6	45864 1·78	54800 2·14	63932 2·49	68500 2·67	73064 2·85	82200 3·20	91728 3·56
21"	30208 1·12	40276 1·50	45312 1·68	50565 1·87	60417 2·24	70485 2·62	75521 2·80	80553 2·99	90625 3·36	101130 3·74
22"	33154 1·17	44203 1·57	49731 1·76	55495 1·96	66308 2·35	77357 2·74	82885 2·94	88407 3·13	99462 3·52	110511 3·92
23"	36242 1·23	48313 1·64	54354 1·84	60400 2·05	72473 2·46	84550 2·87	90591 3·07	96627 3·28	108709 3·69	120786 4·09
24"	39456 1·28	52606 1·71	59184 1·92	65757 2·14	78912 2·56	92062 2·99	98640 3·21	105212 3·42	118368 3·85	131518 4·27
25"	42812 1·34	57081 1·78	64218 2·00	71662 2·23	85625 2·67	99898 3·12	107031 3·34	114162 3·56	128437 4·01	142706 4·45
26"	46306 1·39	61730 1·85	69459 2·08	77510 2·31	92612 2·78	108045 3·24	115765 3·47	123478 3·70	138918 4·17	154351 4·63
27"	49936 1·44	66579 1·92	74904 2·16	83587 2·40	99873 2·88	116516 3·36	124841 3·61	133159 3·85	149809 4·33	166452 4·81
28"	53704 1·50	71602 1·99	80556 2·24	89893 2·49	107408 2·99	125306 3·49	134260 3·74	143205 3·99	161112 4·49	179010 4·98
29"	57608 1·55	76801 2·07	86412 2·32	96429 2·58	115217 3·10	134417 3·61	144024 3·87	153617 4·13	172825 4·65	192025 5·16
30"	61650 1·60	82197 2·14	92475 2·40	103194 2·67	123300 3·20	143847 3·74	154125 4·01	164394 4·27	184950 4·81	205497 5·34
31"	65828 1·66	87768 2·21	98742 2·48	110188 2·76	131657 3·31	153596 3·86	164571 4·14	175536 4·41	197485 4·97	219425 5·52
32"	70144 1·71	93521 2·28	105216 2·56	117411 2·85	140288 3·42	163665 3·90	175702 4·27	187043 4·56	210432 5·13	233809 5·70
33"	74596 1·76	99458 2·35	111894 2·64	124864 2·94	149193 3·52	174054 4·11	186491 4·41	198196 4·70	223789 5·29	248651 5·87
34"	79186 1·82	105577 2·42	118779 2·72	132546 3·03	158372 3·63	184763 4·24	197965 4·54	211154 4·84	237558 5·45	263949 6·05

RECTANGULAR BEAMS

Table 5-d.

fc=600 psi, ft.=16000 psi, m=15

Safe load uniformly distributed lbs/r.ft. including wt. of beam.

Size b×d	B.M. Ft. Lbs	At Sq. in.	Effective Span in Feet									
			6	7	8	9	10	12	14	16	18	20
8"×8"	4053	·42	905	695	507	400	324	224	165	127	103	81
8"×10"	6333	·54	1405	1035	792	625	506	350	258	198	161	127
8"×12"	9120	·65	2250	1485	1140	900	730	505	372	285	232	184
8"×14"	12413	·75	2720	1992	1551	1205	992	677	506	388	311	248
8"×16"	16212	·86	2600	2850	2026	1600	1295	898	657	507	412	324
8"×18"	20519	·92		3340	2570	2022	1638	1135	836	642	522	410
8"×20"	25332	1·08			3169	2500	2020	1400	1030	792	645	506
8"×22"	30652	1·18				2950	2442	1690	1250	958	780	613
8"×24"	36478	1·30					2910	2010	1485	1140	930	729
8"×26"	42811	1·40					3420	2370	1740	1340	1110	856
10"×10"	7920	·68	1760	1290	990	782	634	440	323	247	196	154
10"×12"	11405	·86	2530	1800	1430	1125	912	632	465	356	281	228
10"×14"	15516	·93	3380	2540	1950	1535	1240	862	634	485	380	310
10"×16"	20265	1·06	4500	3320	2540	2000	1640	1130	830	631	500	405
10"×18"	25648	1·20		4200	3200	2530	2220	1430	1045	800	634	513
10"×20"	31665	1·30		5170	3960	3130	2530	1750	1292	990	782	633
10"×22"	38315	1·46			4780	3780	3130	2120	1562	1195	946	766
10"×24"	45597	1·60				4550	3780	2530	1860	1430	1130	902
10"×26"	53514	1·73				5290	4550	2970	2180	1670	1330	1070
10"×28"	62066	1·86					5290	3440	2540	1940	1540	1241

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Size b×d	B.M. Ft.Lbs.	At Sq.in.	Effective Span in Feet.									
			6	7	8	9	10	12	14	16	18	20
12"×12"	13680	·97	3200	2230	1700	1350	1080	760	558	427	338	274
12"×14"	18620	1·13	4140	3040	2330	1840	1490	1035	760	581	460	372
12"×16"	24320	1·30	5400	3960	3200	2400	1940	1350	990	760	600	486
12"×18"	30780	1·46		5000	3840	3050	2450	1705	1255	960	756	616
12"×20"	38000	1·62		6200	4750	3760	3040	2110	1550	1185	937	760
12"×22"	45980	1·76			5750	4550	3680	2560	1875	1435	1135	920
12"×24"	54720	1·94				5400	4370	3040	2230	1710	1350	1094
12"×26"	64220	2·10					5130	3560	2620	2050	1580	1284
12"×28"	74480	2·26						4140	3040	2330	1835	1490
12"×30"	85500	2·42						4750	3480	2670	2110	1710

RECTANGULAR BEAMS

Table 5-e.

fc=750 psi, ft.=18,000 psi, m=15

Safe load uniformly distributed lbs/r.ft. including wt. of beam.

Size b x d	B.M. Ft. Lbs.	At Sq. in.	Effective Span in Feet.									
			6	7	8	9	10	12	14	16	18	20
8"× 8"	5376	·51	1195	880	672	532	430	295	219	168	133	107
8"×10"	8400	·64	1870	1370	1050	830	672	466	343	262	207	168
8"×12"	12096	·77	2680	1970	1512	1195	970	670	494	378	298	242
8"×14"	16464	·90	3660	2690	2058	1630	1322	915	675	515	407	329
8"×16"	21504	1·02	4770	3500	2688	2120	1730	1190	877	672	530	430
8"×18"	27216	1·15	6050	4430	3402	2690	2180	1510	1110	850	670	544
8"×20"	33600	1·28			4200	3320	2690	1865	1370	1050	830	672
8"×22"	38976	1·41			4820	3850	3120	2160	1580	1240	962	780
8"×24"	48384	1·54				4750	3870	2680	1980	1510	1190	968
8"×26"	56784	1·66					4550	3150	2320	1780	1400	1135

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Size b×d	B. M. Ft. Lbs.	At Sq. in.	*Effective Span in Feet.* 6	7	8	9	10	12	14	16	18	20
10"×10"	10500	·8	2330	1710	1310	1035	840	584	428	318	259	210
10"×12"	15120	·96	3360	2460	1890	1490	1210	840	617	472	373	302
10"×14"	20580	1·12	4570	3360	2560	2150	1645	1140	837	643	509	412
10"×16"	26880	1·28	6000	4400	3360	2660	2150	1500	1100	810	667	538
10"×18"	34020	1·44		5500	4250	3360	2720	1900	1390	1062	840	680
10"×20"	42000	1·60			5250	4150	3360	2340	1720	1310	1035	840
10"×22"	50820	1·76			6350	5020	4050	2820	2070	1585	1255	1016
10"×24"	60480	1·92				5970	4840	3360	2470	1885	1490	1210
10"×26"	70985	2·08					5670	3940	2900	2205	1755	1419
10"×28"	82300	2·24						4580	3360	2570	2035	1656
12"×12"	18148	1·15	4020	2960	2270	1790	1450	1008	740	566	447	363
12"×14"	24696	1·34	5420	4020	3087	2430	1970	1370	1000	770	610	494
12"×16"	32256	1·54	7160	5260	4032	3190	2580	1790	1321	1005	795	645
12"×18"	40824	1·73		6670	5103	4030	3260	2260	1660	1275	1005	816
12"×20"	50400	1·92			6300	4970	4300	2790	2050	1575	1240	1008
12"×22"	60984	2·11				6000	4870	3370	2470	1900	1500	1220
12"×24"	72576	2·30					5800	4010	2950	2270	1790	1451
12"×26"	85176	2·49						4720	3470	2660	2100	1704
12"×28"	98784	2·69						5470	4010	3090	2430	1975
12"×30"	113400	2·88						6300	4620	3540	2800	2227

NOTE.—Shear Intensity more than 75 lbs/sq. in. to left of Vertical Line.

CHAPTER 6

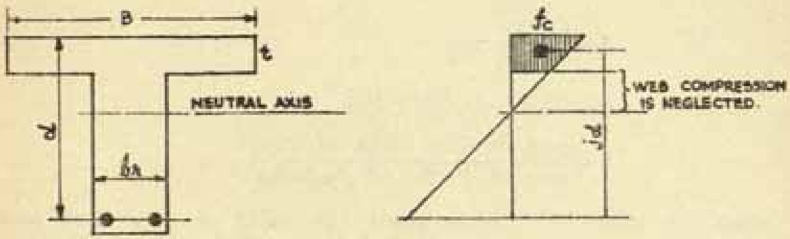
DESIGN OF T-BEAMS, L-BEAMS, ETC.

CONTENTS

CHAPTER 6

T-BEAMS OR L-BEAMS

In practice in case of T-beams, the thickness of the table 't'



Stresses in a T-Beam.

is the same as the thickness of slab already calculated to span between the beams. The width of the slab (B) which is supposed to act as top flange of the beam cannot be determined theoretically but is assumed as:

	Old L. C. C. R.	D.S.I.R. Code or I.SI. Code B.S. Code or New L.C.C.R.
T beam	$\frac{\text{effective span}}{4}$ or Distance between ribs or 12t	$\frac{\text{effective span}}{3}$ or Distance between ribs or 12t+b
L beams	4t	$\frac{\text{effective span}}{6}$ or ½ Distance between ribs or 4t+b

The practical procedure followed and formulæ used in design of T beams are therefore as follows:—

t and B are known, the value of d the effective depth is assumed from practical and economical or architectural considerations. For smaller value of d the amount of tension steel is more, for bigger values of d it is less. The most suitable value of d will therefore depend upon the relative cost of steel and concrete and the following formula is sometimes used to find it approximately.

$$d = \sqrt{\frac{rm}{f_t b_r}} + \frac{t}{2}$$

m=B.M. in inch lbs.

$$r = \frac{\text{cost of 4.38 cwts. of steel}}{\text{cost of 1 cft. of concrete}}$$

when the value of d is assumed, the value of lever arm also requires to be assumed by judgment. This value will vary from $d - \frac{t}{2}$ to $d - \frac{t}{3}$. In case of thin slab and deep beam, the value will be nearer to $d - \frac{t}{2}$ and in case of thick slab and shallow beam, the value will be nearer to $d - \frac{t}{3}$.

Since slabs in buildings are rarely thicker than 6″ we may say for practical purposes that the value of lever arm is say upto .95d for deep beams and .89d for comparatively shallow beams. On these assumptions the amount of tensile steel A_T can be found from charts 6-1 and 6-2.

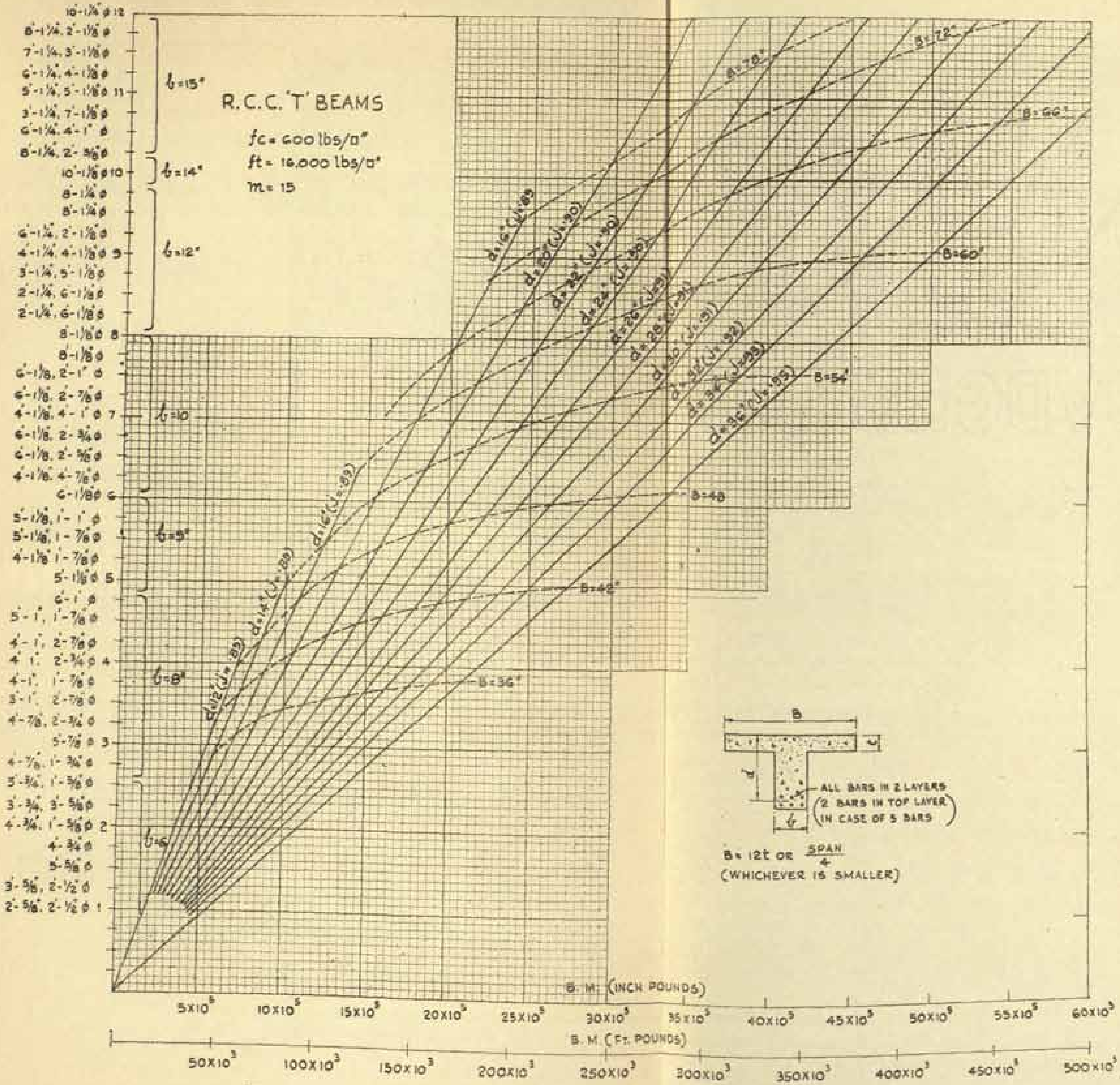
Value of lever arm $= d - \frac{t}{2}$ errs on the safe side and gives slightly more steel.

If further accuracy is required, charts Nos. 6-3, 6-4, 6-5 and table 6-a or formulæ on the next page may be used, as follows:—

Find the value of $Q = \frac{M}{Bd^2}$ and ratio t/d.

Find from chart 6-3, 6-4 or 6-5 the fc for the above values of Q & t/d. From chart No. 6-6 find the location of neutral axis for the particular value of fc and the table 6-a will give the factor j for the particular value of n and t/d.

The maximum B.M. which a particular beam can take without causing excessive fc is shown by the dotted lines in charts 6-1 and 6-2. Thus for a T beam with d=36″ and B=60″, the



R.C.C. 'T' BEAMS
fc = 600 lbs/□"
ft = 16,000 lbs/□"
m = 15
b = 15"
b = 14"
b = 12"
b = 10
b = 9"
b = 8"
b = 6
B = 72"
B = 66"
B = 60"
B = 54"
B = 48
B = 42"
B = 36"
B
t
d
b
ALL BARS IN 2 LAYERS
(2 BARS IN TOP LAYER IN CASE OF 5 BARS)
B = 12t OR SPAN/4
(WHICHEVER IS SMALLER)
B. M. (INCH POUNDS)
B. M. (FT. POUNDS)
5X10^5
10X10^5
15X10^5
20X10^5
25X10^5
30X10^5
35X10^5
40X10^5
45X10^5
50X10^5
55X10^5
60X10^5
50X10^3
100X10^3
150X10^3
200X10^3
250X10^3
300X10^3
350X10^3
400X10^3
450X10^3
500X10^3

Chart 6-1.

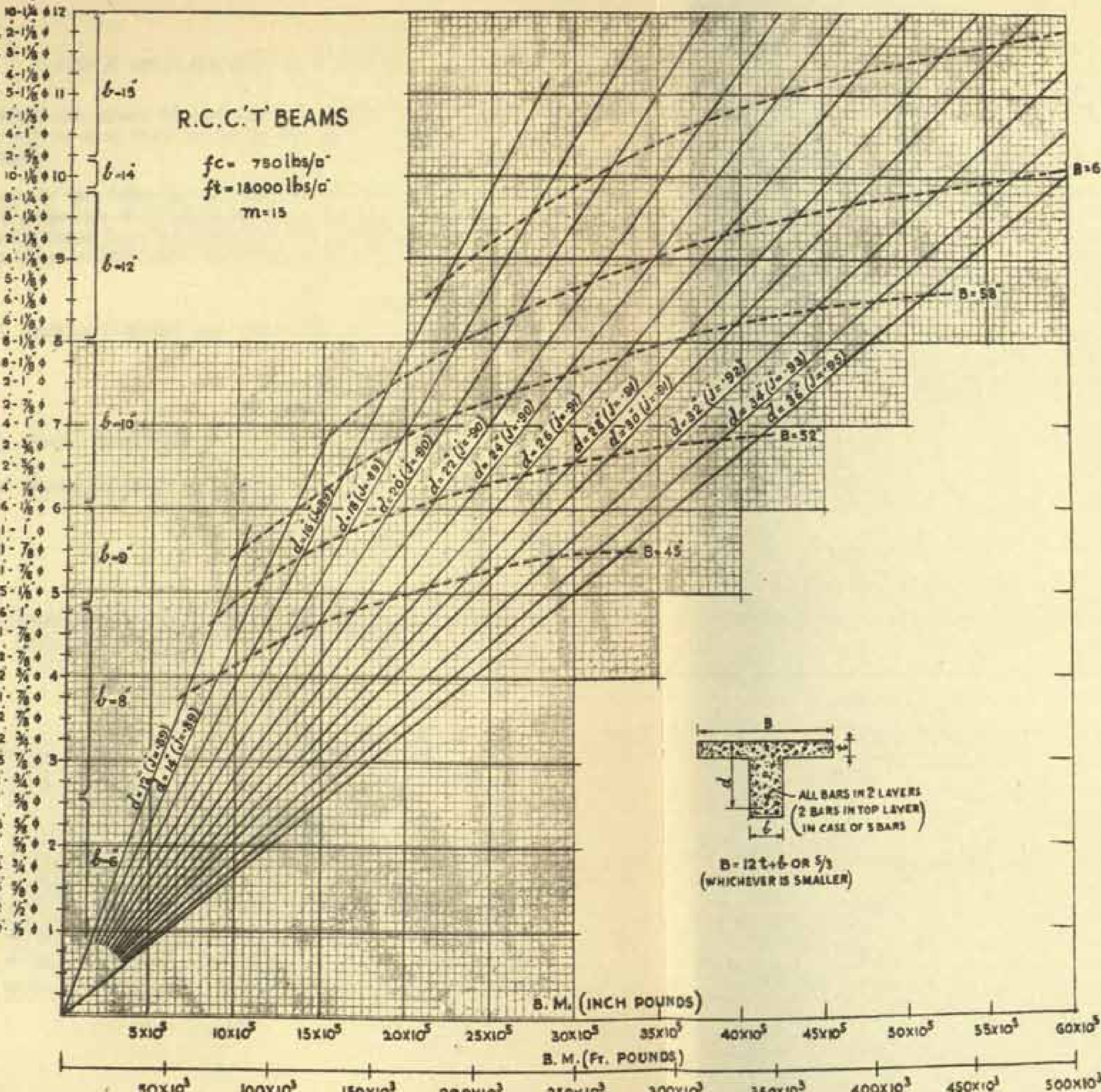

R.C.C. 'T' BEAMS
fc= 750 lbs/□"
ft= 18000 lbs/□"
m=15
B.M. (INCH POUNDS)
B.M. (FT. POUNDS)
5X10^5
10X10^5
15X10^5
20X10^5
25X10^5
30X10^5
35X10^5
40X10^5
45X10^5
50X10^5
55X10^5
60X10^5
50X10^3
100X10^3
150X10^3
200X10^3
250X10^3
300X10^3
350X10^3
400X10^3
450X10^3
500X10^3
b=15"
b=14"
b=12"
b=10"
b=9"
b=8"
b=6"
B=64"
B=58"
B=52"
B=45"
ALL BARS IN 2 LAYERS
(2 BARS IN TOP LAYER IN CASE OF 5 BARS)
B=12t+b OR S/3
(WHICHEVER IS SMALLER)

Chart 6-2.

B.M. should not exceed 50×10^5 inch lbs in chart 6-1. Otherwise fc will be more than permitted and compression steel will be required.

Alternatively the following formulæ can be used for calculations of properties of T beams when approximate values of d and A_T are found from the charts No. 6-1 and 6-2 and the value of B is taken in conformity with code regulations.

(1) Position of neutral axis $$nd = \frac{\frac{Bt^2}{2} + mA_Td}{Bt + mA_T}$$

$$n = \frac{1}{1 + (fs/mfc)}$$

(2) Value of lever arm $$jd = d - \frac{t}{2} + \frac{t^2}{6(2nd - t)}$$

(3) Moment of Resistance $= QBd^2$ in general

$$= fc\left(1 - \frac{t}{2nd}\right)Btjd \quad \text{on concrete}$$

$$= fs \ \ A_T \ \ jd \quad \text{on steel}$$

(Charts Nos. 6-3, 6-4 and table 6-a are based on the above formulæ and are drawn on basis of fs = 16000 or 18000 lbs/□" and m = 15.)

VALUES OF J

n \ t/d	·06	·08	·10	·12	·14	·16	·18	·20	·22	·24	·26	·28	·30	·32	·34	·36	·38	·40
·20	·97	·96	·96	·95	·94	·94	·93	·93										
·25	·97	·96	·95	·95	·94	·93	·93	·92	·92	·92								
·30	·97	·96	·95	·94	·94	·93	·92	·92	·91	·91	·90	·90	·90					
·35	·97	·96	·95	·94	·94	·93	·92	·91	·91	·90	·90	·89	·89	·89	·88			
·40	·97	·96	·95	·94	·93	·93	·92	·91	·90	·90	·89	·89	·88	·88	·87	·87	·87	·87
·45	·97	·96	·95	·94	·93	·93	·92	·91	·90	·89	·89	·88	·88	·87	·87	·86	·86	·85
·50	·97	·96	·95	·94	·93	·93	·92	·91	·90	·89	·89	·88	·87	·87	·86	·85	·85	·84
·55	·97	·96	·95	·94	·93	·92	·92	·91	·90	·89	·88	·88	·87	·86	·85	·85	·84	·84
·60	·97	·96	·95	·94	·93	·92	·92	·91	·90	·89	·88	·87	·87	·86	·85	·85	·84	·83

Table 6-a.

STANDARD T-BEAMS.

The following tables, Nos. 6-b and 6-c, give particulars of simply supported T-beams carrying uniformly distributed load of 1000 to 3000 lbs. per running foot.

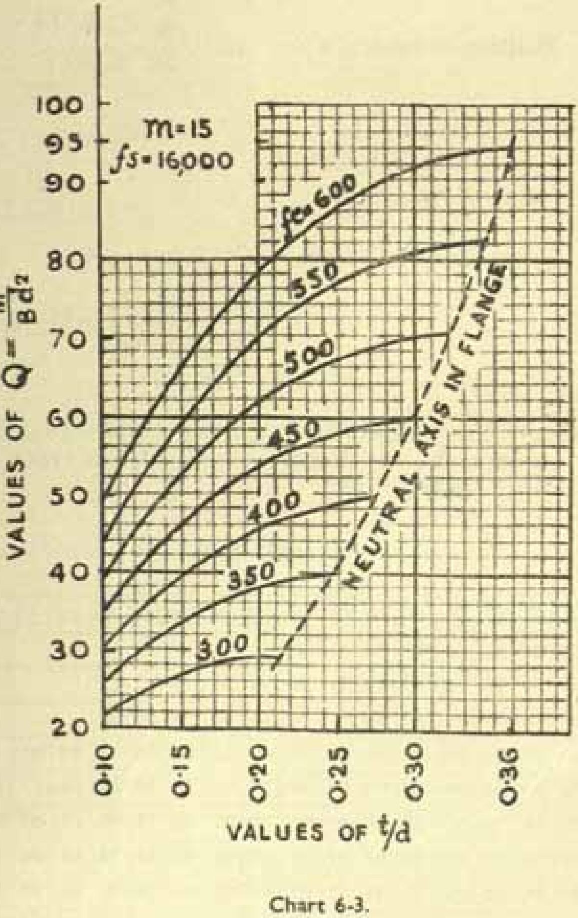


Chart 6-3.

D—Overall depth of beam in inches

br—Thickness of web " "

t—Minimum thickness of flange in inches necessary to keep compression below 600 or 750 lbs./sq. inch as permitted by regulations.

a, b, c, d main steel bars (a and c are in pairs)

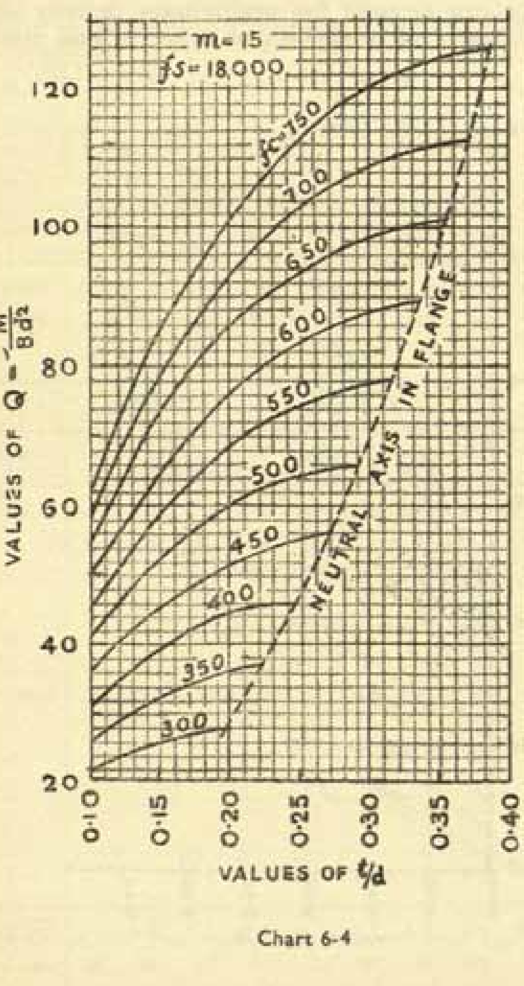


Chart 6-4

K=distance in feet in which shear intensity exceeds 60 or 75 lbs. per sq. inch.=

n_1 number of stirrups in portion AB

n_2 —Do— BC

n_3 —Do— CD

n_4 —Do— DE

(Note: AB=BC=CD) in case of beam with 6 rods

(: AB=BC) Do. 5

These tables can be used for preliminary designs and for approximate estimates of quantities of concrete and steel.

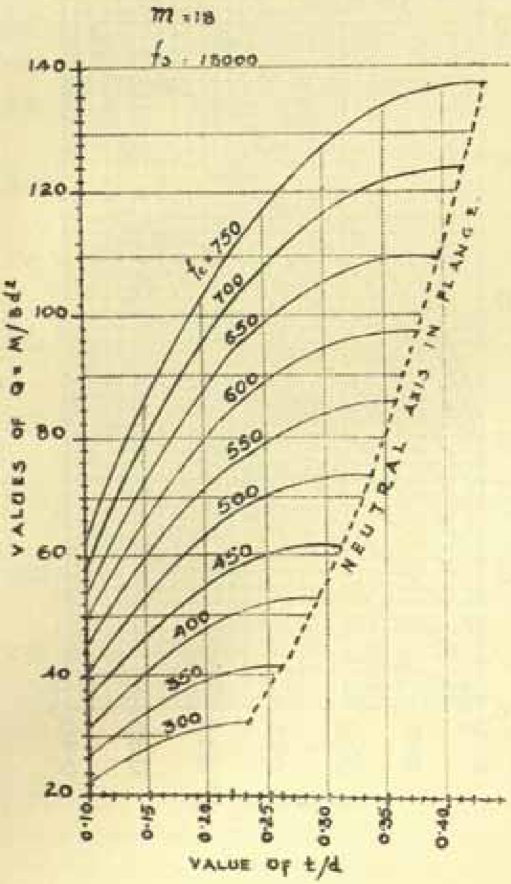


Chart 6-5.

Table 6-b. T-BEAMS. fc=750 psi; ft=18000 psi; m=15

Span=8′–0″ (effective). load=lbs/r.ft. uniform including wt. of beam.

	1000	1200	1400	1600	1800	2000	2200	2400	2600	2800	3000	3200	3400	3600
SECTION	B_1	B_1	B_1	B_1	B_2	B_1	B_2	B_2	B_1	B_2	B_2	B_2	B_2	B_2
Main Steel Sq. Inches.	·6	·7	·8	·8	1·0	1·1	1·2	1·3	1·53	1·53	1·90	1·67	1·9	1·9
a	1/2	1/2	5/8	5/8	1/2	1/2	5/8	5/8	3/4	5/8	5/8	5/8	3/4	3/4
b	1/2	5/8	1/2	1/2	1/2	5/8	1/2	5/8	5/8	5/8	3/4	3/4	5/8	5/8
c					1/2	1/2	1/2	1/2	5/8	5/8	5/8	5/8	5/8	5/8
d														
No. of 3/8″ Strps	9	9	9	9	9	9	9	9	9	9	9	9	9	9
n_1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
n_2	1	1	1	1	1	1	1	1	1	1	1	1	1	1
n_3														
n_4														
K				·25	·7	1·0	1·3	1·5	1·7	1·8	1·8	1·2	1·3	1·5
Concrete C.Ft.	4·5	4·5	4·5	4·5	4·5	4·5	4·5	4·5	4·5	5·1	5·1	7·7	7·7	7·7
Main Steel Lbs.	33	37	40	40	44	48	52	55	65	65	69	74	78	78
Strps Lbs.	10	10	10	10	10	12	12	12	12	12	12	12	12	12

Span=10′–0″ (effective).

SECTION	B_1	B_1	B_1	B_1	B_2	B_2	B_2	B_2	B_2	B_2	B_2	B_2	B_2	B_2
Main Steel Sq. Inches.	·8	1·2	1·22	1·31	1·5	1·67	1·9	2·1	1·9	1·94	2·1	2·21	2·3	2·53
a	5/8	5/8	5/8	5/8	5/8	5/8	3/4	3/4	3/4	5/8	3/4	3/4	5/8	7/8
b	1/2		1/2	5/8	5/8	3/4	5/8	5/8	5/8	3/4	5/8	3/4	1/2	3/4
c		1/2	1/2	1/2	5/8	5/8	5/8	5/8	5/8	3/4	5/8	3/4	3/4	5/8
d														
No. of 3/8″ Strps	10	10	10	10	11	11	13	13	13	13	13	15	15	15
n_1	1	1	1	1	1	1	1	1	1	2	1	1	1	1
n_2					1	1	2	2	2	1	2	2	2	2
n_3												1	1	1
n_4														
K			0·7	1·25	1·25	1·60	2·0	2·2	1·5	1·8	2·0	2·2	2·3	2·5
Concrete C.Ft.	5·5	5·5	5·5	5·5	6·3	6·3	6·3	6·3	9·4	9·4	9·4	9·4	9·4	9·4
Main Steel Lbs.	44	53	60	64	75	80	88	101	89	96	102	108	114	121
Strps. Lbs.	11	11	11	11	12	12	14	14	14	14	14	16	16	16

Span=12′—0″ (Effective) load=lbs/r.ft. uniform including wt. of beam.

	1000	1200	1400	1600	1800	2000	2200	2400	2600	2800	3000	3200	3400	3600
SECTION	B_2	B_2	B_2	B_2	B_2	B_2	B_3	B_3	B_3	B_3	B_3	B_4	B_4	B_4
Main Steel Sq. Inches	1·2	1·43	1·67	1·94	2·21	2·5	2·21	2·3	2·68	2·84	3·0	2·68	2·84	3·0
a	5/8	5/8	5/8	3/4	3/4	3/4	3/4	3/4	7/8	7/8	7/8	7/8	7/8	7/8
b	1/2	1/2	3/4	3/4	3/4	3/4	3/4	7/8	7/8	3/4	7/8	3/4	3/4	7/8
c	3/8	5/8	5/8	5/8	3/4	3/4	3/4	3/4	3/4	7/8	7/8	3/4	7/8	7/8
d														
No. of 3/8″ Strps	14	14	14	14	14	14	14	14	14	18	20	20	18	20
n_1	1	1	1	1	1	1	1	1	1	1	1	2	1	2
n_2	1	1	1	1	1	1	1	1	1	2	2	2	2	2
n_3										1	2	1	1	1
n_4														
K		·4	1·2	1·8	2·2	2·0	1·9	2·2	2·5	2·6	3·0	2·4	2·6	2·8
Concrete C.Ft.	7·4	7·4	7·4	7·4	7·4	7·4	11·0	11·0	11·0	11·0	11·0	14·0	14·0	14·0
Main Steel Lbs.	68	76	90	103	117	123	121	128	143	153	160	152	162	170
Strps. Lbs.	15	15	15	15	15	15	15	15	15	19	21	30	27	30

Span=14′–0″ (effective).

SECTION	B_2	B_2	B_2	B_2	B_3	B_3	B_3	B_3	B_3	B_4	B_4	B_4	B_{12}	B_{12}
Main Steel Sq. Inches	1·67	1·94	2·5	2·68	2·53	2·84	3·00	3·18	3·60	3·13	3·28	3·60	3·28	3·44
a	5/8	3/4	3/4	7/8	7/8	7/8	7/8	7/8	7/8	7/8	7/8	7/8	7/8	7/8
b	3/4	3/4	7/8	7/8	3/4	3/4	7/8	3/4	7/8	7/8	3/4	7/8	3/4	7/8
c	5/8	5/8	3/4	3/4	3/4	7/8	7/8	7/8	7/8	3/4	7/8	7/8	7/8	7/8
d								3/4	7/8	3/4	3/4	7/8	3/4	3/4
No. of 3/8″ Strps	16	16	16	16	16	18	18	24	24	29	24	24	29	31
n_1	1	1	1	1	1	1	1	1	1	1	1	1	2	2
n_2	1	1	1	1	1	2	2	2	2	2	2	2	2	2
n_3								1	1	1	1	1	1	2
n_4								2	2		2	2	1	1
K		1·4	2·2	2·8	2·0	2·5	2·9	3·3	3·5	2·9	3·2	3·4	2·8	3·1
Concrete C.Ft.	8·6	8·6	8·6	8·6	12·7	12·7	12·7	12·7	12·7	16·1	16·1	16·1	17·8	17·8
Main Steel Lbs.	107	123	146	163	160	170	176	210	230	206	218	238	221	231
Strps. Lbs.	17	17	17	17	18	20	20	26	26	30	30	36	54	58

Span=16′–0″ (effective). load=lbs/r.ft. uniform including wt. of beam.

	1000	1200	1400	1600	1800	2000	2200	2400	2600	2800	3000	3200	3400	3600
SECTION	B_2	B_3	B_2	B_3	B_3	B_3	B_4	B_8	B_8	B_{12}	B_{13}	B_{11}	B_{13}	B_{16}
Main Steel Sq. Inches.	1·9	2·21	2·53	2·84	3·13	3·6	3·13	3·6	3·98	3·7	4·02	4·02	4·34	4·53
a	3/4	3/4	7/8	7/8	7/8	7/8	7/8	7/8	1	1	1	1	1	1
b	5/8	3/4	3/4	5/8	5/8	7/8	5/8	7/8	7/8	1	3/4	3/4	7/8	1
c	5/8	3/4	3/4	7/8	7/8	7/8	7/8	7/8	7/8	3/4	1	1	1	1
d					3/4	7/8	5/8	7/8	7/8	3/4	3/4	3/4	7/8	7/8
No. of 3/8″ Strps.	17	17	17	18	20	20	20	20	24	18	24	24	30	30
n_1	1	1	1	1	1	1	1	1	1	1	1	1	2	2
n_2	1	1	1	1	2	2	2	2	2	2	3	3	4	4
n_3				1	1	1	2	2	2	1	3	3	4	2
n_4									2					2
K		1·25	2·2	3·0	3·6	4·0	3·2	3·6	4·0	2·4	2·8	3·2	3·4	3·7
Concrete C.Ft.	14·3	14·3	14·3	14·3	14·3	14·3	18·2	18·2	18·2	29	29	29	29	29
Main Steel Lbs.	107	164	184	204	234	254	240	260	284	271	300	300	320	333
Strps. Lbs.	18	18	18	20	22	22	30	30	36	41	54	54	68	68

Span=18′–0″ (effective).

SECTION	B_2	B_8	B_2	B_3	B_8	B_8	B_8	B_8	B_{10}	B_{10}	B_{11}	B_{10}
Main Steel Sq. Inches.	2·3	2·84	3·13	3·6	4·0	4·0	4·16	4·53	4·34	4·53	4·72	5·14
a	3/4	7/8	7/8	7/8	1	1	1	1	1	1	1	1 1/8
b	7/8	3/4	7/8	7/8	1	7/8	1	7/8	7/8	1	1	1
c	3/4	7/8	3/4	7/8	3/4	7/8	7/8	1	1	1	1	1
d			3/4	7/8	1	7/8	7/8	1	7/8	7/8	1	1
No. of 3/8″ Strps.	19	19	20	20	20	24	24	26	26	28	30	30
n_1	1	1	1	1	1	1	1	1	1	1	2	2
n_2	1	1	1	1	1	2	2	3	3	2	3	3
n_3			1	1	1	2	2	2	2	3	2	2
n_4				1	1	1	1	2	2	2	2	3
K		1·5	2·6	3·4	4·0	3·3	3·8	4·2	3·5	3·9	4·2	4·5
Concrete C.Ft.	16	16	16	16	16	21·5	21·5	21·5	26·8	26·8	26·8	26·8
Main Steel Lbs.	188	228	243	277	303	309	323	352	348	359	372	403
Strps. Lbs.	21	21	22	22	22	36	36	58	58	63	68	68

Span=20′–0″ (effective). load=lbs/r.ft. uniform including wt. of beam.

	1000	1200	1400	1600	1800	2000	2200	2400	2600	2800
SECTION	B[illegible]	B[illegible]	B[illegible]	B[illegible]	B[illegible]	B[illegible]	B[illegible]	B_{10}	B_{11}	$B_{1[illegible]}$
Main Steel Sq. Inches	2·88	3·28	4·00	4·53	4·16	4·72	5·14	4·72	5·14	5·57
a	⅞	⅞	1	1	1	1	1⅛	1	1⅛	1
b	¾	⅞	1	1	1	1	1	1	1	1⅛
c	⅞	¾	¾	1	⅞	1	1	1	1	1⅛
d		⅞	1	⅞	⅞	1	1	1	1	1⅛
No. of ⅜″ Strps.	21	21	21	21	24	24	26	24	26	28
n_1	1	1	1	1	1	1	1	1	1	1
n_2	1	1	1	1	2	2	2	2	2	2
n_3				1	1	2	2	2	2	2
n_4						1	2		2	3
K	1	2·5	3·6	4·4	3·6	4·2	4·7	3·6	4·2	4·5
Concrete C.Ft.	17·7	17·7	17·7	17·7	22·3	22·3	22·3	29·5	29·5	29·5
Main Steel Lbs.	247	272	327	371	346	391	425	397	431	467
Stirrups Lbs.	23	23	23	23	36	36	39	54	58	63

Table 6-c. **T-BEAMS.** f_c=600 psi, f_t=16000 psi, m=15.

Span=8′–0″ (effective). load=lbs/r.ft. uniform including wt. of beam.

	1000	1200	1400	1600	1800	2000	2200	2400	2600	2800	3000	3200	3400	3600
SECTION	B_1	B_1	B_1	B_1	B_1	B_1	B_1	B_1	B_1	B_1	B_1	B_2	B_2	B_2
Main Steel Sq. Inches.	·59	·70	·81	·92	1·10	1·31	1·31	1·53	1·53	1·80	1·80	1·94	1·80	1·80
a	1/2	1/2	5/8	5/8	5/8	5/8	5/8	5/8	5/8	3/4	3/4	3/4	3/4	3/4
b	1/2	5/8	1/2	5/8	1/2	5/8	5/8	5/8	5/8	5/8	5/8	3/4	5/8	3/4
c					1/2	1/2	1/2	5/8	5/8	5/8	5/8	5/8	5/8	5/8
d														
No. of 3/8″ Strps	8	8	10	10	11	11	12	12	12	14	15	17	15	15
n_1	2	2	2	2	1	1	1	1	1	1	2	2	2	2
n_2					1	1	1	2	2	2	2	2	2	2
n_3							1	1	1	2	2	2	1	1
n_4														
K			·6	1·0	1·3	1·6	1·8	2·0	2·1	2·3	2·4	2·3	1·9	2
Concrete C.ft.	4·5	4·5	4·5	4·5	4·5	4·5	4·5	4·5	4·5	4·5	4·5	5·1	7·7	7·7
Main Steel Lbs.	33	37	40	43	52	56	56	64	64	74	74	79	74	74
Stirrups Lbs.	9	9	11	11	11	11	13	13	13	15	17	19	20	20

Span=10′–0″ (effective).

SECTION	B_1	B_1	B_1	B_1	B_2	B_2	B_2	B_2	B_3	B_3	B_3	B_3	B_3	B_4
Main Steel Sq. Inches.	·92	1·31	1·31	1·53	1·72	1·94	2·07	2·21	2·07	2·24	2·38	2·65	2·65	3·41
a	5/8	5/8	5/8	5/8	3/4	3/4	3/4	3/4	3/4	3/4	3/4	3/4	3/4	7/8
b	5/8	5/8	5/8	5/8	3/4	3/4	5/8	3/4	5/8	5/8	3/4	3/4	3/4	3/4
c		1/2	1/2	5/8	1/2	5/8	3/4	3/4	3/4	5/8	5/8	3/4	3/4	3/4
d										3/4	3/4	3/4	3/4	3/4
No. of 3/8″ Strps	11	12	12	12	12	12	16	16	16	20	20	22	22	24
n_1	2	1	1	1	2	1	1	1	2	2	2	2	2	2
n_2		1	1	1	1	1	2	2	1	2	2	2	2	2
n_3						1	2	2	1	1	1	1	1	1
n_4										2	2	3	3	4
K	·2	1·0	1·6	2·0	2·0	2·3	2·6	2·7	2·2	2·4	2·6	2·7	2·9	3·0
Concrete C.ft.	5·5	5·5	5·5	5·5	6·3	6·3	6·3	6·3	9·4	9·4	9·4	9·4	9·4	9·4
Main Steel Lbs.	49	67	67	85	80	92	99	104	101	107	111	125	125	138
Stirrups Lbs.	11	12	12	12	13	12	18	18	20	26	26	27	27	36

Span=12′–0″ (effective). load=lbs/r.ft. uniform including wt. of beam.

	1000	1200	1400	1600	1800	2000	2200	2400	2600	2800	3000	3200	3400	3600
SECTION	B_3	B_2	B_2	B_2	B_2	B_3	B_4	B_3	B_3	B_4	B_5	B_6	B_5	B_6
Main Steel Sq. Inches	1·42	1·67	1·92	2·21	2·42	2·69	2·69	2·72	2·90	3.02	3·38	3·29	3·64	4·00
a	⅝	⅝	¾	¾	⅞	⅞	⅞	⅞	1	⅞	1	⅞	⅞	1
b	½	¾	¾	¾	⅞	⅞	⅞	⅝	¾	1	⅞	¾	1	1
c	⅝	⅝	⅝	¾	⅝	¾	¾	⅞	¾	⅞	⅞	⅞	⅞	⅞
d												¾	¾	¾
No. of ⅜″ Strps.	13	13	13	13	13	14	17	17	17	20	23	25	32	35
n_1	1	1	1	1	1	1	1	1	2	2	2	1	1	1
n_2	1	1	1	1	1	1	1	2	2	1	2	3	2	3
n_3					1	2	1	1	1	2	3	2	2	2
n_4												2	2	2
K	·6	1·5	2·2	2·7	3·0	3·3	2·7	3·0	3·2	3·4	3·6	3·1	3·3	3·5
Concrete C.Ft.	7·4	7·4	7·4	7·4	7·4	7·4	11·0	11·0	11·0	11·0	11·8	14·0	14·0	14·0
Main Steel Lbs.	79	89	103	116	125	139	143	148	156	169	178	185	200	225
Strps. Lbs.	14	14	14	14	14	15	18	18	18	21	24	26	33	36

Span=14′–0″ (effective).

SECTION	B_2	B_2	B_2	B_2	B_4	B_3	B_4	B_4	B_4	B_7	B_7	B_7	B_8	B_8
Main Steel Sq. Inches.	1·8	2·21	2·65	3·0	2·37	3·2	3·37	3·56	3·93	3·61	3·98	4·16	3·2	4·16
a	¾	¾	⅞	1	¾	⅞	⅞	1	1	⅞	1	1	1	1
b	⅝	¾	⅞	¾	⅞	1	⅞	1	1	⅞	⅞	1	⅞	1
c	⅝	¾	¾	¾	⅞	⅞	1	⅞	1	⅞	⅞	⅞	⅞	⅞
d										⅞	⅞	⅞	⅞	⅞
No. of ⅜″ Strps.	15	15	16	21	15	16	20	22	25	23	26	26	28	30
n_1	1	1	1	1	1	1	1	1	1	1	2	2	2	2
n_2	1	1	1	2	1	1	2	2	2	2	2	2	2	2
n_3			2	4	1	2	3	4	6	2	2	2	2	2
n_4										4	5	5	5	6
K	1·6	2·5	3·1	3·6	3·0	3·4	3·7	4·0	4·1	3·7	4·0	4·1	4·2	4·4
Concrete C.Ft.	8·6	8·6	8·6	8·6	12·7	12·7	12·7	12·7	12·7	16·1	16·1	16·1	17·8	17·8
Main Steel Lbs.	120	142	168	180	155	202	214	225	247	240	263	274	269	281
Strps. Lbs.	16	16	17	23	16	17	30	33	38	46	52	52	63	68

Span—16′–0″ (effective). load—lbs/r.ft. uniform including wt. of beam.

	1000	1200	1400	1600	1800	2000	2200	2400	2600	2800	3000	3200	3400	3600
SECTION	B_4	B_4	B_4	B_4	B_4	B_4	B_4	B_7	B_7	B_7	B_8	B_8	B_8	B_8
Main Steel Sq. Inches.	2·1	2·41	2·78	3·24	3·65	4·02	4·37	4·16	4·34	4·71	4·53	4·71	5·14	5·86
a	¾	⅞	1	1	1	1	1	1	1	1	1	1	1⅛	1⅛
b	⅞	⅞	⅞	1	⅞	1	1	1	1	1	1	1	1	1⅛
c	⅝	⅝	¾	¾	¾	¾	1	⅞	⅞	1	1	1	1	1
d					⅞	1	¾	⅞	1	1	⅞	1	1	1
No. of ⅜″ Strps.	17	16	17	17	21	25	31	25	29	31	29	29	35	35
n_1	1	1	1	1	1	1	1	1	1	1	1	2	2	2
n_2	1	1	1	1	1	1	2	2	2	2	2	2	3	3
n_3					1	1	2	2	2	2	2	2	3	2
n_4					2	4	5	2	4	5	4	4	6	7
K	·8	2·0	2·9	3·5	4·0	4·4	4·7	4·1	4·5	4·7	4·3	4·4	4·6	4·8
Concrete C.ft.	14·3	14·3	14·3	14·3	14·3	14·3	14·3	18·2	18·2	18·2	20·0	20·0	20·0	20·0
Main Steel Lbs.	155	175	217	228	259	282	310	290	313	340	330	341	367	384
Strps. Lbs.	26	24	26	26	32	38	47	50	58	62	65	65	80	80

Span—18′–0″ (effective).

SECTION	B_4	B_4	B_4	B_4	B_8	B_7	B_7	B_7	B_8	B_8	B_8	B_8
Main Steel Sq. Inches.	2·69	3·01	3·61	4·16	4·71	4·16	4·52	5·13	4·95	5·34	5·76	5·96
a	⅞	⅞	⅞	1	1	1	1	1⅛	1⅛	1⅛	1⅛	1⅛
b	⅞	⅞	⅞	1	1	1	1	1	1	1⅛	1⅛	1⅛
c	¾	⅞	⅞	⅞	1	⅞	1	1	1	1	1⅛	1⅛
d			⅞	⅞	1	⅞	1	1	⅞	1	1	1⅛
No. of ⅜″ Strps.	19	19	19	19	25	23	25	27	29	31	33	37
n_1			1	1	1	1	1	1	1	2	1	2
n_2			1	1	1	2	2	2	2	2	2	2
n_3			1	1	1	1	2	2	2	2	2	2
n_4			1	2	5	2	4	5	5	6	8	9
K	1·8	3·0	3·9	4·5	5·0	4·4	4·8	5·2	5·3	5·6	5·8	6·0
Concrete C.Ft.	16·0	16·0	16·0	16·0	15·4	19·0	19·0	19·0	22·2	22·2	22·2	22·2
Main Steel Lbs.	214	237	294	334	380	342	377	420	417	445	487	502
Strps. Lbs.	29	29	29	29	38	46	50	54	65	70	75	84

Span=20′ (effective). load=lbs/r.ft. uniform including wt. of beam.

	1000	1200	1400	1600	1800	2000	2200	2400	2600	2800	3000	3200	3400	3600
SECTION	B_2	B_4	B_3	B_8	B_7	B_8	B_6	B_9	B_8	B_9				
Main Steel Sq. Inches	3·13	3·81	4·53	4·99	4·71	5·36	5·79	6·0	6·1	6·7				
a	7/8	1	1	1⅛	1	1⅛	1⅛	1⅛	1⅛	1⅛				
b	7/8	7/8	1	1⅛	1	1⅛	1⅛	1⅛	1⅛	1⅛				
c	3/4	7/8	1	7/8	1	1	1⅛	1⅛	1	1⅛				
d	3/4	3/4	7/8	1	1	1	1	1⅛	1	1⅛				
No. of 3/8″ Strps	19	19	21	25	23	23	27	29	35	39				
n_1	1	1	1	1	1	1	1	1	2	2				
n_2	1	1	1	1	2	2	2	2	2	2				
n_3	1	1	1	1	1	2	2	1	2	2				
n_4			2	4	3	4	4	6	8	10				
K	2·8	4·0	4·8	5·5	4·9	5·4	5·8	5·7	6·1	6·4				
Concrete C.Ft.	17·0	17·0	17·0	17·0	21·0	21·0	21·0	24·5	24·5	24·5				
Main Steel Lbs.	262	316	372	404	401	462	489	515	516	573				
Stirrups Lbs.	29	29	32	38	46	46	54	66	79	88				

NOTE:

(a) Bearing assumed = D − 1 Inches.

(b) Quantities should be considered approximate. They are given on basis of: Total length of Beam = Effective Span + (D-1)″ & t = 4″. The quantity of concrete is in web only. Steel includes anchor bars also.

Standard sections of T-beams used in Table Nos. 6-b & 6-e.

(all figures show inches)

	B_1	B_2	B_3	B_4	B_5	B_6	B_7	B_8	B_9	B_{10}
D	13	13	16	16	16	19	19	19	22	22
br	8	9	10	10	10	10	10	10	10	12
t	3	3	3	4	4½	3	4	4½	4½	3

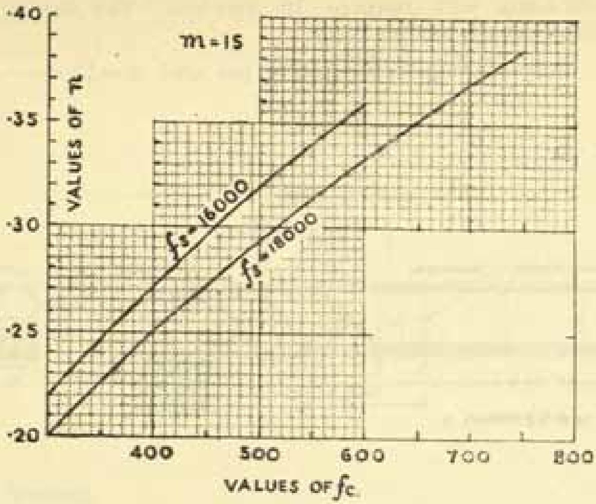


Chart 6-6.

Example :—

Find the section of a simply supported T-beam 18′ effective span carrying a load of 1600 lbs. per running foot.

From Chart 6-2:

$$M = \frac{1600 \times 18^2}{8} = 64800 \text{ ft. lbs.}$$

$$= 65 \times 10^3 \text{ ,, (say)}$$

for d = 14″ A_T = 4 sq inches.

From tables 6-b:

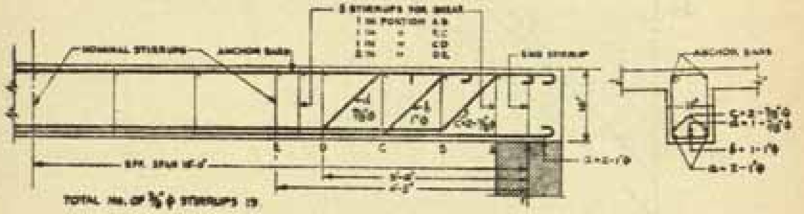
section reqd. = B_4 i.e. 16″ × 10″

A_T = 4.16 □″ i.e. 3—1″c & 3—⅞″c

shear steel will be required for a distance of 4.5 ft. from the support and 5 stirrups of ⅜″ c will be required in this portion.

The whole beam will require 19 stirrups. The sketch below gives all the details of the beam.

(fc=600 psi, ft=16000 psi and m=15)



CHAPTER 7

SHEAR

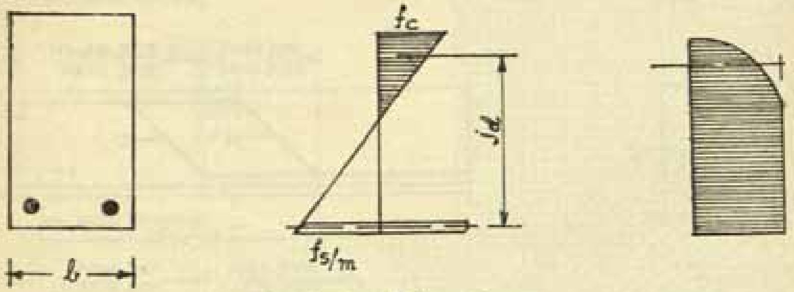
CONTENTS

CHAPTER 7

SHEAR

7.1 GENERAL.

The shear intensity can be considered as uniform over the area bjd of a concrete beam.



Distribution of Shear Stress.

The shear stress therefore is $\frac{S}{bjd}$ lbs/sq inch.

when S is the vertical shear in lbs., b and d are breadth and depth of beam in inches, respectively.

This stress must not exceed $\frac{fc}{10}$ otherwise separate shear reinforcement is necessary. If the intensity exceeds $\frac{3fc}{10}$ it is necessary to enlarge the section of the beam.

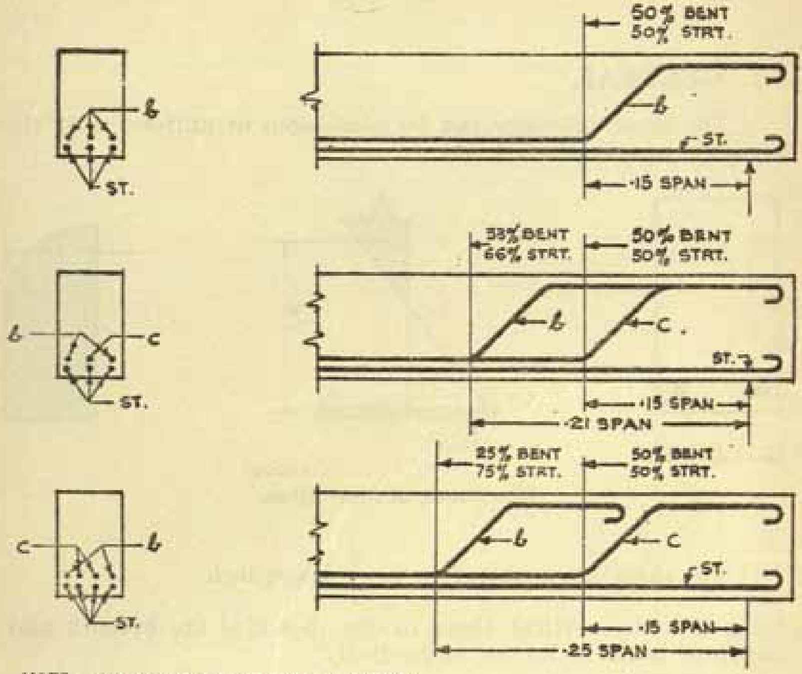
Provision for shear is made generally by:

(a) Inclined bars.

(b) Vertical stirrups.

(a) In ordinary practice special inclined bars are not provided but bars which form the tensile reinforcement are bent up to take shear in such portions of the beam where due to reduction of the bending moment they are no longer necessary for the tensile stress. The points where tensile bars can be bent up are found by drawing the B.M. diagram to scale, on which tensile value of each bar can be sketched to scale.

The following sketches give the location of the point at which part of the tensile steel can be bent up, in case of uniformly distributed load on a simply supported beam.



Bending of bars for Shear.

The shearing resistance of inclined bars is given in Tables 7-a and 7-b. The distance from support of an uniformly loaded simply supported beam, for which shear steel is required for a particular shear intensity at support is given in Tables 7-c and 7-d.

(b) If the vertical binders are spaced at a distance p, there will be $\frac{jd}{p}$ number of binders in a length equal to lever arm of the beam. Then the shear resistance in this portion which is $\frac{Aftjd}{p}$ equals the shear S (A is the area of both the vertical arms of stirrup). The values of $\frac{Aft}{p}$ for different sizes and

(Continued on page 151)

R. C. C. BEAMS. STIRRUP SPACING CHART.

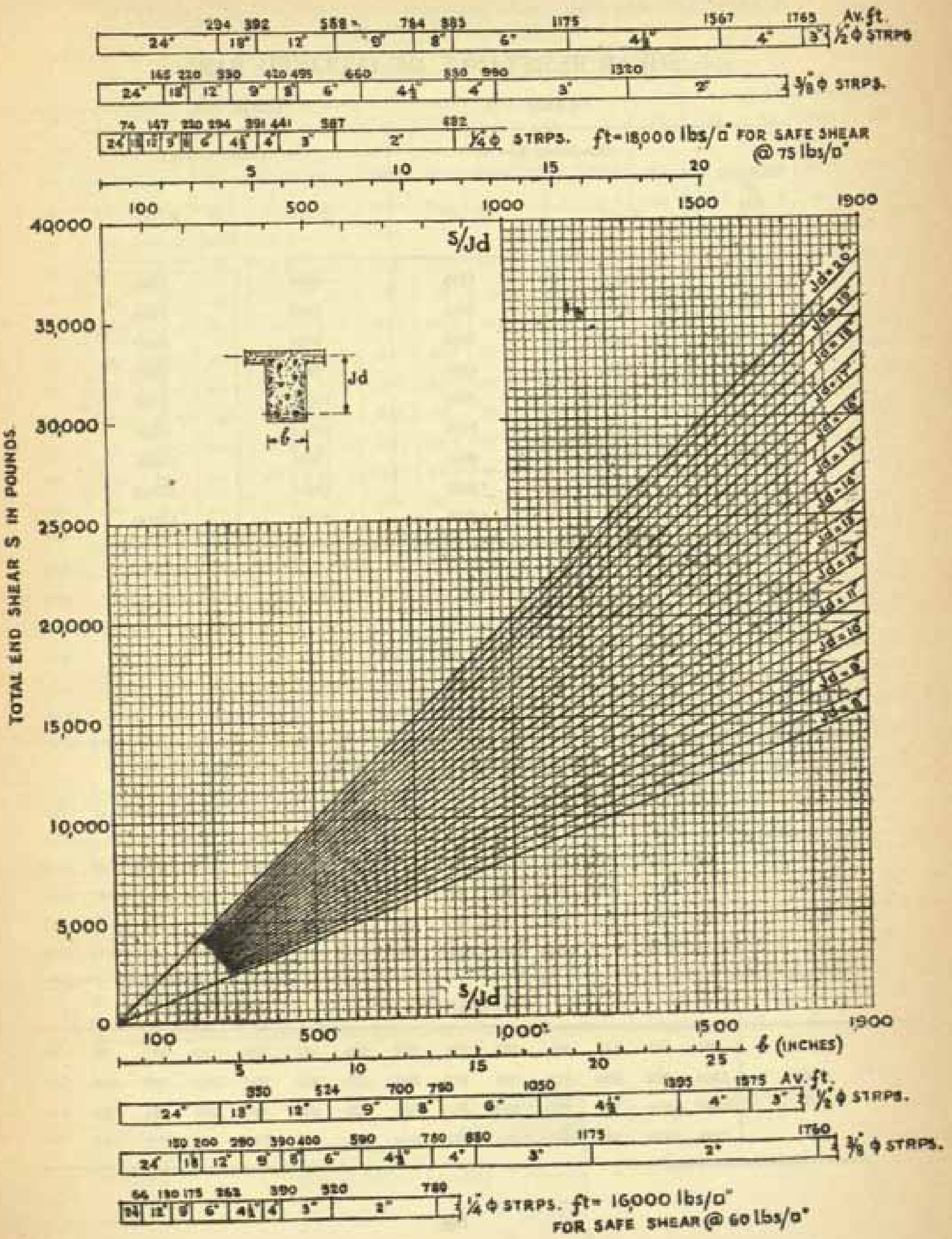


Chart 7-1.

SHEAR RESISTANCE OF INCLINED BARS

Table 7-a. / Table 7-b.

Diameter of Bar	ft.=16000 Lbs./□"		ft.=18000 Lbs./□"	
	θ=45°	θ=30°	θ=45°	θ=30°
1/2"	2220	1575	2500	1750
5/8"	3470	2460	3900	2750
3/4"	5000	3550	5600	3900
7/8"	6802	4830	7650	5400
1"	8884	6300	10000	7050
1⅛"	11244	7950	12650	8950
1¼"	13882	9850	15600	11050
1⅜"	16800	11920	18900	13350
1½"	19994	14150	22500	15900

Table 7-e.

Diameter of Bar	VALUES OF S/jd i.e. A ft/p.										ft=16000 Lbs/□"			
	2"	3"	4"	4½"	5"	6"	7"	7½"	8"	9"	12"	15"	18"	24"
1/4"	782	522	392	348	314	262	224	208	195	175	130	104	86	66
5/16"	1225	817	613	545	490	408	350	327	306	273	204	163	136	102
3/8"	1760	1175	880	783	705	587	503	470	440	391	293	235	196	147
1/2"	3130	2096	1571	1395	1258	1048	898	840	787	700	524	419	350	261

Table 7-f.

ft=18000 Lbs/□"

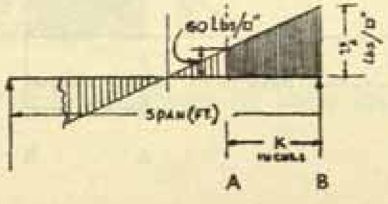
1/4"	882	587	441	391	355	294	252	235	221	196	147	117	98	74
5/16"	1386	924	693	616	554	462	396	370	347	308	231	183	154	115
3/8"	1980	1320	990	880	792	660	566	528	495	440	330	264	220	165
1/2"	3530	2350	1765	1567	1412	1175	1008	940	883	784	588	472	392	294

Table 7-c.

Distance along beam span requiring shear steel (for safe shear at 60 lbs. per sq. inch.)

Note:—Figures tabulated give value of "k" in inches.

Vs. \ Sp.	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
200	42	46·4	50·4	54·6	58·6	63	67·2	71·4	75·7	79·7	84	88·2	92·4	96·6	100·1
195	41·5	45·6	49·8	54	58·2	62·3	66·5	70·6	74·8	78·7	83	87·2	91·3	95·5	99·5
190	41	45·2	49·3	53·2	57·4	61·5	65·6	69·8	74	77·9	82	86·1	90·2	94·3	98·4
185	40·5	44·6	48·6	52·8	56·7	60·8	64·8	68·9	73	77.	81	85	89·1	93·2	97·2
180	40	44	48	52·1	56	60	64	68	72	76	80	84	88	92	96
175	39·5	43·4	47·3	54·4	55·2	59·1	63·2	67	71	75	79	83	87	91	94·7
170	39	40·8	46·6	50·6	54·3	58·2	62·2	65·9	70	74	78	82	85	89·6	93·5
165	38	41·8	45·8	49·7	53·4	57·2	61·1	64·6	68·8	72·2	76	79·8	83·6	87·5	91·2
160	37·5	41·3	45	48·8	52·5	56·3	60	63·7	67·5	71·3	75	77·8	82·5	86·3	90
155	37	40·5	44·2	47·8	51·5	55·4	58·9	62·5	66·5	70·2	74	76·8	81·4	85	88
150	36	39·7	43·2	46·8	50·4	54	57·7	61·2	64·8	68·4	72	75·6	79·2	83	86·4
145	35	38·8	42·2	45·7	49	52·4	56·3	59·5	63	66·5	70	74·6	77	80·5	84
140	34·3	37·8	41·2	44·6	48	51·4	54·8	58·2		65·1	68·6	72	75·5	79	82·4
135	33·4	36·7	40	43·4	46·6	50	53·3	56·6	60	63·4	66·7	70	73·4	76·8	80
130	32·3	35·5	38·8	42	45·2	48·5	51·7	54·8	58·2	61·4	64·6	68	71·2	74·4	77·6
125	31·2	34·3	37·5	40·6	43·7	46·8	50	53·2	56·3	59·4	62·4	66·2	68·7	71·9	75
120	30	33	36	39	42	45	48	51	54	57	60	63	66	69	72
115	28·7	31·5	34·4	37·2	40·2	43	46	48·8	51·5	54·4	57·4	60·2	63	65·9	68·7
110	27·3	30·1	32·8	35·5	38·2	41	43·7	46·3	49·2	51·8	54·6	57·4	60	62·8	65·6
105	25·7	28·3	30·9	33·5	36	38·6	41·2	43·6	46·4	48·9	51·5	54	56·7	59·2	61·8
100	24	26·4	28·8	31·2	33·6	36	38·4	40·8	43·2	45·7	48	50·5	52·8	55·2	57·7
95	22	24·2	26·4	28·6	30·8	33	35·2	37·4	39·6	41·8	44	46·2	48·4	50·6	52·8
90	20	22	24	26	28	30	32	34	36·0	38	40	42	44	46	48
85	17·6	19·4	21·5	23	24·7	26·4	28·2	30·8	31·7	33·4	35·2	37	38·8	40·5	42·3
80	15	16·5	18	19·5	21	22·5	24	25·5	27	28·5	30	31·5	33	34·5	36
75	12	13·4	14·4	15·6	16·8	18	19·2	20·4	21·6	22·8	24	25·2	26·4	28·8	29·8
70	8·5	9·4	10·4	11·2	12	12·8	13·7	14·5	15·4	16·3	17·1	18	18·7	19·7	20·3
65	4·6	5·1	5·6	6	6·5	7	7·4	7·8	8·35	8·8	9·3	9·74	10·2	10·7	11·1
60	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0



$v_s = \dfrac{\text{SHEAR AT SUPPORT}}{b \times jd}$

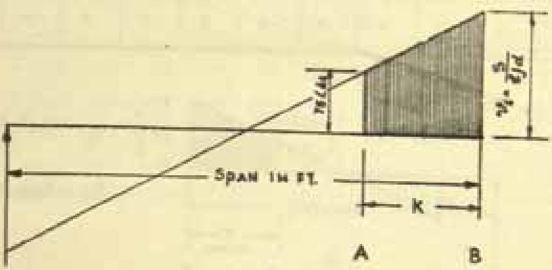
Sp.—Span in feet.

Table 7-d.

Distance along beam span requiring shear steel (for safe shear at 75 lbs./□″)

(Note:—Figures tabulated give value of "k" in inches)

Vs. \ Sp.	10′	11′	12′	13′	14′	15′	16′	17′	18′	19′	20′	21′	22′	23′	24′
200	37·5	41·2	45	48·7	52·5	56·2	60	63·7	67·5	71·2	75	78·8	82·5	86·2	90
195	36·9	40·6	44·3	48	51·7	55·4	59	62·8	66·5	70·2	74	77·6	81·3	85	88·7
190	36·32	40	43·5	47·2	50·8	54·4	58	61·7	65·2	69	72·5	76·2	79·8	83·5	87
185	35·7	39·3	42·8	46·4	50	53·6	57·2	60·8	64·3	68	71·5	75	78·6	82·2	85·8
180	35	38·5	42	45·5	49	52·5	56	59·5	63	66·5	70	73·5	77	80·6	84
175	34·3	37·7	41·2	44·6	48	51·5	54·8	58·3	61·7	65·2	68·6	72	75·5	79	82·4
170	33·5	37	40·3	43·6	47	50·3	53·7	57	60·4	63·8	67·2	70·5	74	77·2	80·7
165	32·7	36	39·3	42·5	45·8	49	52·3	55·6	59	62·2	65·5	68·7	72	75·3	78·6
160	31·9	35·1	38·3	41·5	44·7	47·8	51·1	54·2	57·5	60·7	63·8	67	70·3	73·5	76·7
155	31	34·1	37·2	40·3	43·4	46·5	49·7	52·7	55·8	59	62	65·2	68·2	71·4	74·3
150	30	33	36	39	42	45	48	51	54	57	60	63	66	69	72
145	29	31·9	34·8	37·7	40·6	43·5	46·5	49·4	52·2	55·2	58	61	64·9	66·6	69·7
140	27·9	30·7	33·5	36·3	39·1	41·9	44·7	47·5	50·2	53	56	58·7	61·5	64·2	67
135	26·7	29·4	32	34·7	37·4	40	42·8	45·6	48·1	50·7	53·4	56·1	58·6	61·4	64·1
130	25·4	27·8	30·5	33	35·6	38·1	40·7	43·2	45·7	48·2	50·9	53·4	56	58·5	61
125	24	25·4	28·8	31·2	33·6	36	38·4	40·8	43·2	45·7	48	50·5	52·8	55·2	57·7
120	22·5	24·8	27	29·3	31·5	33·8	36	38·3	40·5	42·7	45	47·3	49·3	51·8	54
115	20·1	22·1	24·1	26·1	28·2	30·2	32·2	34·2	36·2	38·2	40·2	42·2	44·2	46·2	48·2
110	19	20·9	22·8	24·7	26·6	28·5	30·4	32·3	34·2	36·1	38	40	41·8	43·7	45·6
105	17·2	18·9	20·6	22·4	24·1	25·8	27·5	29·3	31	32·7	34·4	36·1	37·9	39·6	41·3
100	15	16·5	18	19·5	21	22·5	24	25·5	27	28·5	30	31·5	33	34·5	36
95	12·6	13·8	15·1	16·4	17·6	18·9	20·4	21·4	22·7	23·9	25·2	26·5	27·7	29	30·2
90	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
85	7	7·7	8·4	9·1	9·8	10·5	11·2	11·9	14·4	15·2	16	16·8	17·6	18·4	19·6
80	3·8	4·1	4·5	4·9	5·3	5·6	6	6·4	6·8	7·2	7·5	7·9	8·2	8·7	9
75						—	N	I	L	—					



Sp.=Span in feet.

spacings of stirrups are given in Tables 7-e and 7-f. From these tables spacing of stirrups in a particular portion of a beam can be found: (see example).

7.2 EXAMPLE.

Find the pitch of stirrups at the end portion of a 20′ span, 20″×10″ beam with end shear S of 24000 lbs. 2—1″ ϕ bars are available for being bent up.

2—1″ ϕ @ 45° give 18000 lbs.

Balance to be provided by stirrups=6000 lbs.

$$S/jd = \frac{6000}{20 \times .88} = 340$$

Hence ¼″ stirrups should be placed at 4½″ ϕs. It is necessary to calculate the spacing of stirrups at various points as shown and arrange them properly, in a practical and simple manner.

Explanation of chart No. 7-1.

This chart can be used for any type of shear diagram but it is more useful in case of triangular shear diagram; the use will be understood from example below:—

Example above

Balance S=6000 lbs. jd=17.6″ say 17.5 for chart.

¼″ stirrups @ 4½″ are required according to the chart.

Find stirrups for the whole beam as above when no bars are available for bending up.

S/jd=1365 from chart so S/bjd=136.

Shear taken by concrete @ 60 lbs.=10800 lbs. from chart. Stirrups are required from portion A to B of the beam; length AB=66″ from Table No. 7-e. This much length is given by 31 divisions in the chart.

So the spacing of ½″ stirrups is—

4½″ for 13 divisions from support i.e. $\frac{13}{31} \times 66 = 28''$ say

6″	10	,,	=21″ ,,
8″	4	,,	= 8″ ,,
9″	4″	,,	= 8″ ,,
			65″

Total length to be reinforced for shear checks with Table No. 7-e.

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

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CHAPTER 8

DESIGN OF R.C. COLUMNS

CONTENTS

CHAPTER 8

R.C. COLUMNS

8.1 GENERAL FORMULAE.

The general formula for design of columns loaded with axial loads is

$$P = \left\{ \begin{array}{l} \text{the load carried by} \\ \text{a short column} \end{array} \right\} \begin{array}{l} = \text{Concrete stress} \times \text{Concrete area} \\ + \text{Steel stress} \times \text{steel area} \end{array}$$

(a) *Concrete Area* is assumed as follows:—

Old L.C.C.R. d^2: Core area (shown hatched in para 8.3 (b) less area of steel. Av.

New L.C.C.R. & D.S.I.R. Code D^2: Gross cross sectional area—area of steel—area of champhers.

(b) *Steel area* is the area of longitudinal bars only.

(c) *Concrete stress* & modular ratios. (stress in lbs per sq. inch)

Old L.C.C.R.	600	1 : 2 : 4 mix	m=15
	750	1 : 1 : 2 mix	m=12
New L.C.C.R.	1000	1 : 1 : 2	(A quality)
	780	1 : 1 : 2	(Ordinary)
	880	1 : 1½ : 3	(A quality)
	680	1 : 1½ : 3	(Ordinary)
	760	1 : 2 : 4	(A quality)
	600	1 : 2 : 4	(Ordinary)
	m=15		

D.S.I.R. Code same as above. Concrete styled high grade in place of A quality.

I.S.I. Code
900 1 : 1 : 2
750 1 : 1½ : 3
600 1 : 2 : 4

In case of old L.C.C.R. concrete stress can be increased to some extent if extra volume of lateral binding is used as given in Statement in para 8.2; in this case the value of m is to be taken as $\dfrac{9000}{\text{increased stress}}$

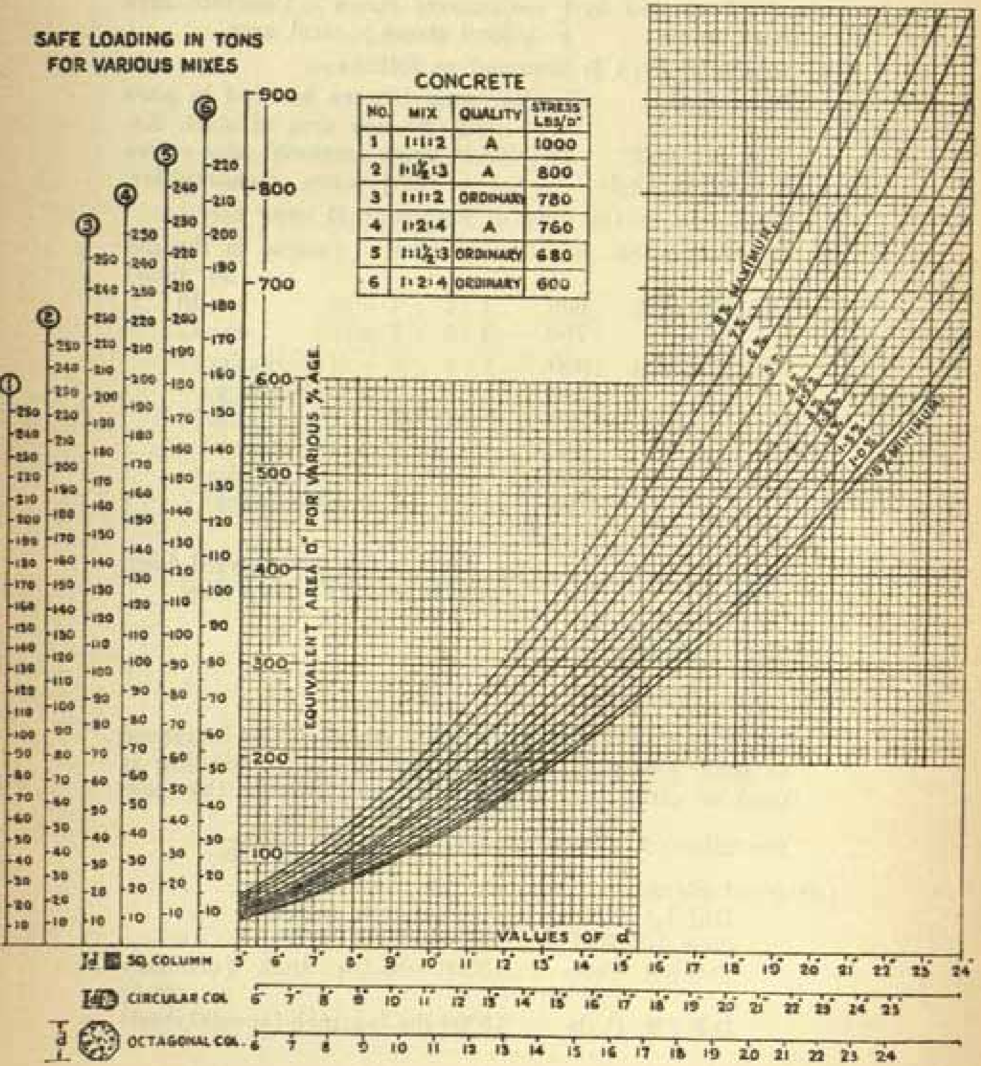
(d) *Steel Stress*

Old L.C.C.R.	m × concrete stress
New L.C.C.R.	m × concrete stress
D.S.I.R. Code	13500 lbs./sq. inch (ordinary steel)
D.S.I.R. Code	15000 lbs./sq. inch (special steel)

Value of safe loading in different types of columns calculated on above principles are given in Chart No. 8-1 and Table No. 8-a.

I.S.I. Code }
B.S. Code } 18,000 lbs./sq. inch.

R.C.C. COLUMNS
(NEW L.C.C. BY-LAWS)



NO.	MIX	QUALITY	STRESS LBS/□"
1	1:1:2	A	1000
2	1:1½:3	A	800
3	1:1:2	ORDINARY	780
4	1:2:4	A	760
5	1:1½:3	ORDINARY	680
6	1:2:4	ORDINARY	600

Chart 8-1

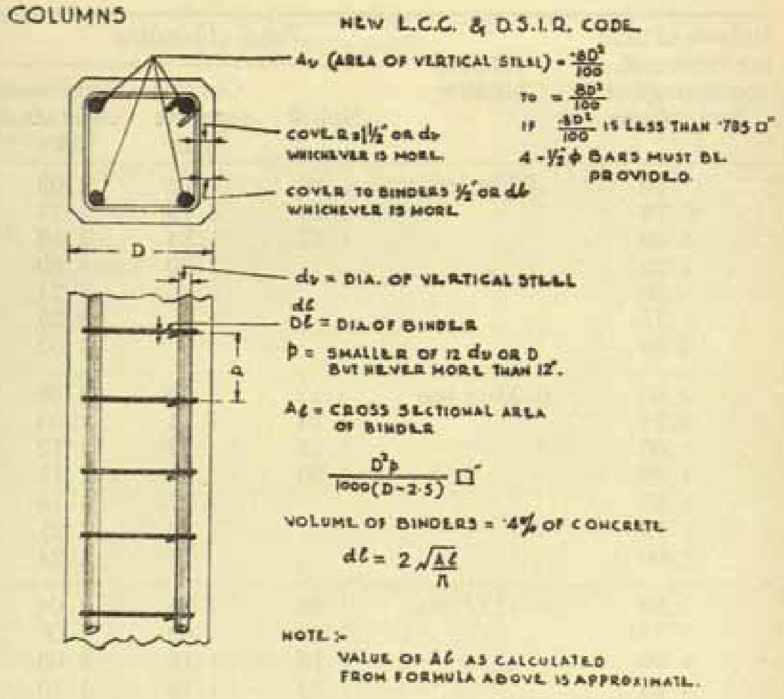
8.2 INCREASED COMPRESSIVE STRENGTH.

Cross binding of the longitudinal reinforcement of columns adds to the compressive strength of the concrete to some extent. The following increment in stress permitted by old regulations may be noted.

Volume of binding expressed as percentage of core volume	Pitch of binding	Form of binding		
		Spiral	Circular separate links	Rectilinear separate links
.50	.2d or less	1.16	1.12	1.08
0.75		1.24	1.18	1.12
1.00		1.32	1.24	1.16
1.25			1.30	1.20
1.50				1.24
1.75				1.28
2.00				1.32
0.50	0.3d or less	1.12	1.09	1.06
0.75		1.18	1.14	1.09
1.00		1.24	1.18	1.12
1.25		1.30	1.23	1.15
1.50			1.27	1.18
1.75			1.32	1.21
2.00				1.24
0.50	0.4d or less	1.08	1.06	1.04
0.75		1.12	1.09	1.06
1.00		1.16	1.12	1.08
1.25		1.20	1.15	1.10
1.50		1.24	1.18	1.12
1.75		1.28	1.21	1.14
2.00		1.32	1.24	1.16
0.50	0.5d or less			1.02
0.75				1.03
1.00				1.04
1.25				1.05
1.50				1.06
1.75				1.07
2.00				1.08
Any percentage	0.6d			1.00

NOTE:—The concrete stress can never be increased to more than $1\frac{1}{3}$ fc viz. 800 lbs/sq. inch.

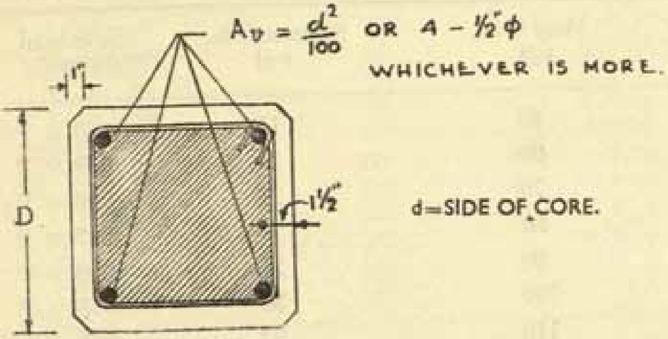
8.3 DETAILS OF COLUMNS.

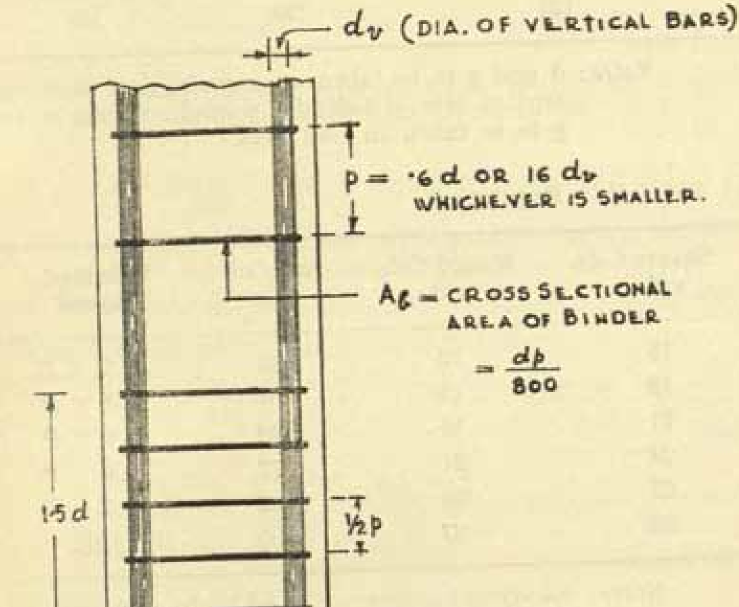


Note:

Where it is necessary to splice the longitudinal reinforcement the rods must be lapped in contact with one another, the length of the lap being not less than 24″.

OLD L.C.C.R


$A_v = \frac{d^2}{100}$ OR 4 – ½″ φ
WHICHEVER IS MORE.
1″
D
1½″
d=SIDE OF CORE.


d_v (DIA. OF VERTICAL BARS)
P = ·6 d OR 16 d_v
WHICHEVER IS SMALLER.
A_b = CROSS SECTIONAL AREA OF BINDER
$= \frac{dp}{800}$
1·5 d
½ p
END

8.4 EFFECT OF SLENDERNESS OF COLUMNS ON SAFE LOAD P.

(a) *New L.C.C. Regulations.*

Any Cols. v/g	Square Cols. v/d	Safe load allowed.
50	15	1.0 × P
60	18	0.9 × P
70	21	0.8 × P
80	24	0.7 × P
90	27	0.6 × P
100	30	0.5 × P
110	33	0.4 × P
120	36	0.3 × P
121	39	Nil

Notes: d and g to be taken on gross section basis, except in case of helically wound columns where g to be taken on core basis.

(b) *Old L.C.C. Regulations.*

Square Cols. v/d	Round Cols. v/d	Any Col. v/g	Safe load allowed
15	12	45	1.0 × P
18	15	54	0.8 × P
21	18	63	0.6 × P
24	21	72	0.4 × P
27	24	82	0.2 × P
30	27	90	Nil

Notes: v=virtual length. See table on next page.
d=effective diameter of column measured across core in direction of lateral supports which determine its length.
g=least equivalent radius of gyration ascertained on the core area.

D.S.I.R. Code of Practice

Rectangular & round Cols. v/d	Any Col. v/g	Safe load allowed
15	50	1.0 × P
18	60	0.9 × P
21	70	0.8 × P
24	80	0.7 × P
27	90	0.6 × P
30	100	0.5 × P
33	110	0.4 × P
36	120	0.3 × P
39	130	0.2 × P
42	140	0.1 × P
45	150	Nil

Relation between virtual length 'v' & actual length 'l'.

Old L.C.C.R.

i Both ends of column fixed in position & direction: $v=l$

ii One end of column fixed in position & direction and one end fixed in position only (hinged) $v=1.4l$

iii Both ends fixed in position only and not in direction: $v=2l$

iv One end fixed in position and direction and one end free e.g. a mast, flagstaff, etc. $v=4l$

Note: l is taken as clear distance between lateral supports.

New L.C.C.R. & D.S.I.R. Code of Practice:

	Cols. of 1 storey	Cols of 2 storeys & above
i Both ends fixed in position & direction	$v = 0.75\ l$	$0.75\ l$
ii Both ends fixed in position & not in direction	l	0.75 to 1 l
iii One end fixed in position & direction and		
One end imperfectly fixed in both position and direction	1 to 2 l	1 to 2 l

Note: length 'l' is measured as follows.

D.S.I.R. Code of Practice

l : to be measured between upper surfaces of two floors affording lateral support or to be the clear distance between supports plus the lateral dimension of the column.

New L.C.C.R.

l : to be the actual length with single storey columns and to be the distance from floor level to floor level with other columns.

8.5 HELICAL BINDING OF COLUMNS.

Old L.C.C.R.

Safe stress in concrete can be increased to 1.33fc as already stated.

New L.C.C.R. and D.S.I.R. Code

The safe stress on concrete cannot be increased as above but additional load of 2tbAb (i.e. 27000 Ab lbs, tb being 13500 lbs for both codes) can be allowed on the column. However the safe load on the column is to be calculated on core area basis and not on gross area basis.

Thus $P = P_c + P_T + P_B$ where

P_c = load carried by concrete in core

P_T = " " vertical steel

P_B = additional load due to helical binding

= 2tbAb = 27000 Ab

Ab = volume of helical binding per unit length of column.

The pitch of helicals not to be more than 3″ or 1/6 of core diameter whichever is less. For practical reasons not more than $\frac{1}{2}''\phi$ bars and not less than 3/16″ dia. should be used for forming the helical binding. The values of P_B for different column size and arrangement of helical windings can be found from the Chart 8-2.

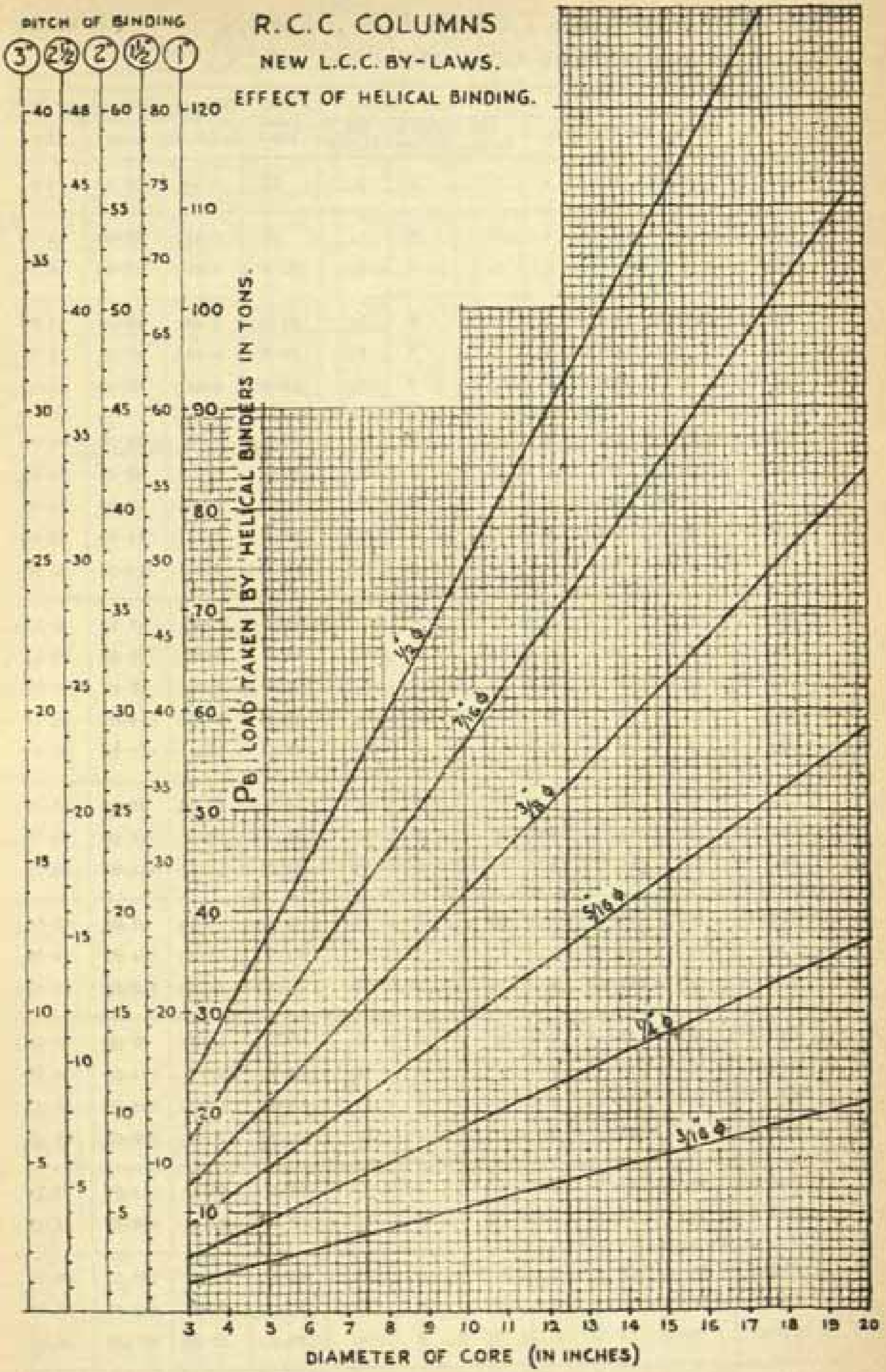

R.C.C COLUMNS
NEW L.C.C. BY-LAWS.
EFFECT OF HELICAL BINDING.
PITCH OF BINDING
3"
2½"
2"
1½"
1"
P_B LOAD TAKEN BY HELICAL BINDERS IN TONS.
½" φ
7/16" φ
3/8" φ
5/16" φ
¼" φ
3/16" φ
DIAMETER OF CORE (IN INCHES)

Chart 8-2

8.6 CHARTS AND TABLES FOR DESIGN. Table 8-a

SQUARE COLUMNS (New L.C.C.R.)

Ref.	D Inches	d Inches	Av. Nos.	Av. Dia. Inches	Strps. Pitch Inches	Strps. Dia. Inches	Safe Load Tons	Concrete C. Ft. in 10' Ht	Steel Lbs./10' Ht. Main	Steel Lbs./10' Ht. Strps.
C1	6"	3	4	½	4	¼	13	2·36	28·00	9·5
C2a	8"	5	4	½	6	⅜	20	4·35	28·00	19·70
C2b	8	5	4	⅝	6	⅜	21·5	4·35	43·68	19·70
C3a	9	6	4	½	6	⅜	24·7	5·48	28·00	22·30
C3b	9	6	4	⅝	7	⅜	26·0	5·48	43·70	19·11
C3c	9	6	4	¾	7	⅜	28·4	5·48	63·00	19·11
C4a	10	7	4	½	6	⅜	29·8	6·75	28·00	24·96
C4b	10	7	4	⅝	6	⅜	31·4	6·75	43·68	24·96
C4c	10	7	4	¾	6	⅜	33·5	6·75	63·00	24·96
C4d	10	7	4	⅞	6	⅜	34·5	6·75	85·68	24·96
C4e	10	7	4	1	6	⅜	38·0	6·75	114·81	24·96
C5a	12	9	4	⅝	6	⅜	43·2	9·86	43·68	30·17
C5b	12	9	4	¾	6	⅜	45·3	9·86	63·00	30·17
C5c	12	9	4	⅞	6	⅜	47·6	9·86	85·68	30·17
C5d	12	9	4	1	6	⅜	50·4	9·86	114·81	30·17
C5e	12	9	8	⅞	6	⅜	56·4	9·86	171·36	30·17
C6a	14	11	4	¾	9	½	59·2	13·55	63·00	35·75
C6b	14	11	4	⅞	10	½	61·5	13·55	85·68	33·19
C6c	14	11	4	1	10	½	64·3	13·55	114·81	33·19
C7a	15	12	4	⅞	9	½	69·3	15·50	85·68	45·08
C7b	15	12	4	1	9	½	72·1	15·50	114·81	45·08
C7c	15	12	4	1⅛	9	½	75·3	15·50	148·72	45·08
C8a	16	13	4	⅞	9	½	77·7	17·7	85·68	48·26
C8b	16	13	4	1	9	½	80·0	17·7	114·81	48·26
C8c	16	13	4	1⅛	9	½	83·7	17·7	148·72	48·26
C8d	16	13	8	1"	9	½	93·1	17·7	229·62	48·26
C9a	18	15	4	1	8	½	98·8	22·4	114·81	62·19
C9b	18	15	4	1⅛	8	½	103·0	22·4	148·72	62·19
C10a	20	17	4	1⅛	8	½	122·0	27·60	148·72	69·33
C10b	20	17	8	1	8	½	132·12	27·60	229·62	69·33
C10c	20	17	8	1⅛	8	½	139·0	27·60	297·44	69·33
C11a	21	18	8	1⅛	8	½	150·0	30·6	297·44	69·33
C11b	21	18	8	1¼	8	½	155·0	30·6	367·00	69·33

Table 8-b
SQUARE COLUMNS (Old L.C.C.R.)

Ref. No.	D Inches	d Inches	Av. Nos.	Av. Dia. Inches	Strps. Pitch Inches	Strps. Dia. Inches	Safe Load Tons	Concrete C.ft. in 10' Ht.	Steel Lbs./10'ht. Main	Steel Lbs./10'ht. Strps.
C1	8	5	4	½	3	3/16	10	4·35	28	9·6
C2	9	6	4	½	3½	3/16	13	5·48	28	9·31
C3a	10	7	4	½	4¼	¼	16	6·75	28	15·3
C3b	10	7	4	⅝	4¼	¼	18	6·75	43·7	15·3
C4a	12	9	4	⅝	4½	¼	26	9·86	43·7	18·5
C4b	12	9	4	¾	4½	¼	28	9·86	63·0	18·5
C4c	12	9	4	⅞	4½	¼	30	9·86	85·7	18·5
C5a	14	11	4	⅝	5½	5/16	37	13·55	43·7	27·0
C5b	14	11	4	¾	5½	5/16	39	13·55	63·0	27·0
C5c	14	11	4	⅞	5½	5/16	42	13·55	85·7	27·0
C5d	14	11	4	1	5½	5/16	44	13·55	114·8	27·0
C6a	15	12	4	¾	7¼	⅜	45	15·5	63	32·6
C6b	15	12	4	⅞	7¼	⅜	48	15·5	85·7	32·6
C6c	15	12	4	1	7¼	⅜	51	15·5	114·8	32·6
C7a	16	13	4	¾	7½	½	52	17·7	63	58·6
C7b	16	13	4	⅞	7½	½	54	17·7	85·7	58·6
C7c	16	13	4	1	7½	½	57	17·7	114·8	58·6
C7d	16	13	4	1⅛	7½	½	60	17·7	148·7	58·6
C8a	18	15	4	⅞	9	½	69	22·4	85·7	54·4
C8b	18	15	4	1	9	½	72	22·4	114·8	54·4
C8c	18	15	4	1⅛	9	½	75	22·4	148·7	54·4
C8d	18	15	8	⅞	9	½	78	22·4	171·4	54·4
C9a	20	17	4	1	9	½"	89	27·6	114·8	60·7
C9b	20	17	4	1⅛	9	½"	91	27·6	148·7	60·7
C9c	20	18	8	⅞	9	½	95	27·6	171·4	60·7
C9d	20	17	8	1	9	½"	100	27·6	229·6	60·7
C10a	22	19	4	1⅛	8	½"	112	33·4	148·7	76·5
C10b	22	19	8	⅞	8	½"	115	33·4	171·4	76·5
C10c	22	19	8	1	8	½"	119	33·4	229·6	91·5
C10d	22	19	8	1⅛	8	½"	126	33·4	297·4	91·5
C11a	24	21	4	1¼	10	⅝"	137	39·9	183·5	105·9
C11b	24	21	8	⅞	10	⅝"	136	39·9	171·4	105·9
C11c	24	21	8	1	10	⅝"	142	39·9	229·6	105·9
C11d	24	21	8	1⅛	10	⅝"	148	39·9	297·4	105·9

SQUARE COLUMNS I.S.I. CODE

Table 8-c.

Size (in)	Longitudinal Steel			Load carried by longitudinal bars at 18,000 lbs. per sq. in.	Load carried by the Column Lbs.		
	Bars No.	Bars Dia.	Area (Sq. in.)	Lbs.	1 : 2 : 4 600 p.s.i.	1 : 1½ : 3 750 p.s.i.	1 : 1 : 2 900 p.s.i.
8	4	½	0·79	14,100	52,100	61,500	70,900
	4	1	3·14	56,600	93,100	102,200	111,300
	4	1¼	4·91	88,400	123,900	132,700	141,600
9	4	½	0·79	14,100	62,300	74,300	86,300
	4	1	3·14	56,600	103,300	115,000	126,600
	8	1	6·28	113,100	158,000	169,100	180,300
10	4	⅝	1·23	22,100	81,300	96,200	110,900
	4	1⅛	3·98	71,600	129,200	143,600	158,000
	8	1⅛	7·95	143,100	198,400	212,100	225,800
11	4	⅝	1·23	22,100	93,900	111,800	129,800
	4	1¼	4·91	88,400	158,100	175,500	191,900
	4	1¾	9·62	173,200	240,000	256,700	274,200
12	4	⅝	1·23	22,100	107,700	129,100	150,500
	4	1⅜	5·94	106,900	189,800	210,700	231,300
	8	1¼	9·82	176,700	257,300	277,500	297,700
13	4	¾	1·77	31,800	132,300	157,300	182,400
	8	1	6·28	113,100	210,700	235,100	259,600
	10	1¼	12·27	220,900	314,900	338,400	361,900
14	4	¾	1·77	31,800	148,600	177,800	206,800
	8	1	6·28	113,100	227,100	255,800	284,100
	8	1½	14·14	254,500	364,500	391,000	418,300
15	6	⅝	1·84	33,100	167,100	200,600	234,100
	8	1¼	9·82	176,700	305,700	338,200	370,200
	12	1⅜	17·82	320,700	445,200	476,200	507,200
16	4	⅞	2·41	43,300	195,500	233,400	271,300
	8	1⅜	11·88	213,800	360,300	396,800	433,800
	8	1¾	19·24	346,400	488,500	524,400	559,400
17	4	⅞	2·41	43,300	215,400	258,300	301,300
	8	1⅜	11·88	213,800	380,000	421,800	462,800
	12	1½	21·21	381,700	542,700	582,700	622,700

Table 8-c (contd).

Size (in)	Longitudinal Steel			Load carried by longitudinal bars at 18,000 lbs. per sq. in.	Load carried by the Column Lbs.		
	Bars No.	Bars Dia.	Area (Sq. in.)	Lbs.	1 : 2 : 4 600 p.s.i.	1 : 1½ : 3 750 p.s.i.	1 : 1 : 2 900 p.s.i.
18	4	1	3·14	56,600	249,600	297,600	345,600
	8	1½	14·14	254,500	440,500	487,000	533,500
	8	2	25·13	452,400	631,900	676,900	721,400
19	4	1	3·14	56,600	271,600	325,100	378,600
	12	1¼	14·73	265,100	473,100	525,100	577,100
	12	1¾	28·86	519,500	719,000	768,500	818,500
20	8	¾	3·53	63,600	301,600	361,100	421,300
	12	1⅜	17·82	320,700	549,700	607,200	664,700
	10	2	31·42	565,500	786,000	841,500	897,000
21	8	¾	3·53	63,600	320,600	391,600	457,600
	8	1¾	19·24	346,400	599,400	662,900	726,400
	10	2	31·42	565,500	811,500	872,500	934,500
22	8	⅞	4·81	86,600	374,300	445,600	518,600
	12	1½	21·21	381,700	659,700	727,700	798,700
	12	2	37·70	678,600	946,600	1,013,600	1,080,600
24	8	⅞	4·81	86,600	429,600	514,600	600,600
	12	1¾	28·86	519,500	847,900	929,500	1,012,000
	18	1¾	43·30	779,300	1,099,300	1,179,300	1,259,300
26	8	1	6·28	113,100	515,100	615,100	716,100
	12	1¾	28·86	519,500	907,500	1,004,500	1,102,000
	16	2	50·27	904,800	1,280,800	1,374,800	1,468,800
28	8	1	6·28	113,110	579,100	696,100	813,100
	12	2	37·70	678,600	1,126,600	1,238,600	1,349,600
	20	2	62·83	1,131,000	1,564,000	1,672,000	1,781,000
30	12	⅞	7·22	129,000	664,000	798,000	933,000
	16	1¾	38·48	692,700	1,209,700	1,337,700	1,467,700
	22	2	69·12	1,244,000	1,743,000	1,867,000	1,992,000
32	12	1	9·43	169,600	778,600	930,600	1,082,600
	16	2	50·27	904,800	1,489,800	1,634,800	1,780,800
	24	2	75·40	1,357,000	1,927,000	2,069,000	2,212,000
34	8	1¼	9·82	176,700	863,700	1,036,700	1,206,700
	16	2	50·27	904,800	1,567,800	1.733,800	1,899,800
	28	2	87·96	1,583,000	2,223,000	2,383,000	2,543,000
36	8	1⅜	11·68	213,800	983,800	1,175,800	1,373,800
	32	1½	56·55	1,018,000	1,762,000	1,947,000	2,134,000
	28	2	87·96	1,583,000	2,307,000	2,488,000	2,671,000

8.7 ESTIMATING TABLES OF FORM WORK, ETC. FOR COLUMNS.

Sectional areas and perimeters of columns

Per foot height

Dia. or Side	Area	Peri-meter.	Area	Peri-meter.	Area	Peri-meter.	Area	Peri-meter.	
8"	·35	2·09	·37	2·21	·39	2·31	·44	2·67	
10"	·55	2·62	·58	2·75	·60	2·88	·69	3·33	
12"	·79	3·14	·83	3·33	·87	3·97	1·00	4·00	
14"	1·07	3·67	1·13	3·88	1·18	4·03	1·37	4·67	
16"	1·40	4·19	1·47	4·42	1·54	4·62	1·78	5·33	NOTE:
18"	1·77	4·72	1·87	4·96	1·95	5·19	2·25	6·00	Cross sectional areas
20"	2·18	5·24	2·30	5·50	2·41	5·78	2·78	6·67	are in sq. ft. and
22"	2·63	5·76	2·78	6·08	2·90	6·35	3·35	7·33	perimeters in linear
24"	3·14	6·28	3·31	6·62	3·46	6·94	4·00	8·00	feet.
26"	3·69	6·81	3·89	7·17	4·06	7·50	4·71	8·67	
28"	4·27	7·34	4·51	7·80	4·72	8·06	5·43	9·33	
30"	4·91	7·86	5·18	8·25	5·41	8·66	6·25	10·00	
32"	5·58	8·39	5·89	8·83	6·15	9·22	7·13	10·67	
34"	6·31	8·90	6·63	9·38	6·94	9·78	8·00	11·33	
36"	7·06	9·43	7·45	9·92	7·78	10·40	9·00	12·00	
SHAPE	ROUND		OCTAGONAL		HEXAGONAL		SQUARE		

SECTIONAL AREAS OF RECTANGULAR COLUMNS

in sq. feet.

SIDES	10"	12"	14"	16"	18"	20"	22"	24"	26"	28"	30"	32"	34"	36"
8"	·55	·67	·78	·89	1·00	1·11	1·22	1·34	1·45	1·56	1·67	1·78	1·89	2·01
10"	·69	·83	·97	1·11	1·25	1·39	1·53	1·67	1·80	1·94	2·08	2·22	2·35	2·49
12"	·83	1·00	1·17	1·33	1·50	1·67	1·83	2·00	2·17	2·33	2·50	2·67	2·83	3·00
14"	·97	1·17	1·37	1·56	1·75	1·95	2·14	2·34	2·53	2·72	2·92	3·12	3·30	3·51
16"	1·11	1·33	1·56	1·78	2·00	2·23	2·45	2·66	2·90	3·11	3·34	3·56	3·78	4·00
18"	1·25	1·50	1·76	2·00	2·25	2·50	2·75	3·00	3·25	3·50	3·75	4·00	4·25	4·50
20"	1·39	1·67	1·95	2·23	2·50	2·78	3·05	3·33	3·62	3·89	4·17	4·48	4·72	5·01
22"	1·53	1·83	2·14	2·44	2·75	3·05	3·25	3·66	3·97	4·27	4·58	4·89	5·18	5·49
24"	1·67	2·00	2·34	2·66	3·00	3·33	3·66	4·00	4·34	4·66	5·00	5·33	5·66	6·00

8.8 ILLUSTRATIVE EXAMPLES.

1. Find suitable reinforcement for a column 16″ x 16″ overall size and supporting a load of 80 tons and to be designed according to stresses for 1 : 2 : 4 ordinary grade concrete specified by new L.C.C.R.

From chart put 1.22% vertical steel i.e. $\frac{256}{100}\,1.22 = 3.14\square''$

i.e. 4—1″ ϕ bars.

2. Find safe load on an octagonal column of 12″ across flats with a reinforcement of 8-7/8″ ϕ bars and 5/16″ helical windings at 1″ pitch.

Diameter of core of column

$$=12'' - (1\tfrac{1}{2}'' + 1\tfrac{1}{2}'') + \left(\frac{5''}{16} + \frac{5''}{16}\right) = 9\tfrac{5}{8}''$$

$\therefore$ Area of core $= \pi\,(9\tfrac{5}{8})^2 \times \tfrac{1}{4} = 72.76\square''$

$\therefore$ Percentage of steel $= \dfrac{4.81 \times 100}{72.76} = 6.6$

$\therefore$ load carried from chart 8-1. = 38 tons

load carried by helical winding from Chart 8-2. = 28 tons

$\therefore$ Total load = 66 tons

3. Find safe load on a rectangular column 10″ x 24″, reinforced with eight $\tfrac{7}{8}''$ ϕ bars made from 1 : 1 : 2 mix ordinary quality.

Percentage of steel $= \dfrac{4.81 \times 100}{24 \times 10} = 2$

Side of corresponding square column $= \sqrt{240} = 15.5$

Safe load from chart by referring to vertical scale No. 3 is 106 tons.

8.9 COLUMNS WITH ECCENTRIC LOAD OR SUBJECTED TO B.M.

Sometimes columns of a building are not loaded axially but the resultant load is eccentric. Especially in case of external columns of a building, a portion of the bending moment from the end of the beams is transferred to the columns, and it is necessary to design the column to stand both direct load and B.M.

Eccentrically loaded columns fall under two cases:

(1) Columns where the whole section is under compression.

(2) Columns where only part of the section is under compression whereas the other portion is under tension.

Case (1) In this case the value of e/d is less than

$\frac{1+ .27p}{6(1+.14p)}$ Thus in the case of columns without steel this value is 1/6 (i.e. the line of load falls within middle third of the section). The stress fc in concrete is given by the formula

$$fc = \frac{P}{bd}\left[\frac{1}{1+.14p} + \frac{e}{d} \times \frac{1}{(.167 + .0448p)}\right]$$

$$= \frac{P}{bd}\,\frac{1}{K}$$

The value of K can be found from the chart 8.3 for various values of p upto 5% and m = 15, $\frac{d}{10}$ being the distance of steel rods from the face of the column.

Case (2) In this case it is necessary to first find out the position of the neutral axis by the formula.

$$n_o^3 + 3\left(\frac{e}{d} - \frac{1}{2}\right)n^2_o + 6mp\,\frac{e}{d}\,n_o - 3mp\left(\frac{2r^2}{d^2} + \frac{e}{d}\right) = 0.$$

DESIGN OF COLUMNS WITH ECCENTRIC LOADS
(WHOLE SECTION IN COMPRESSION)

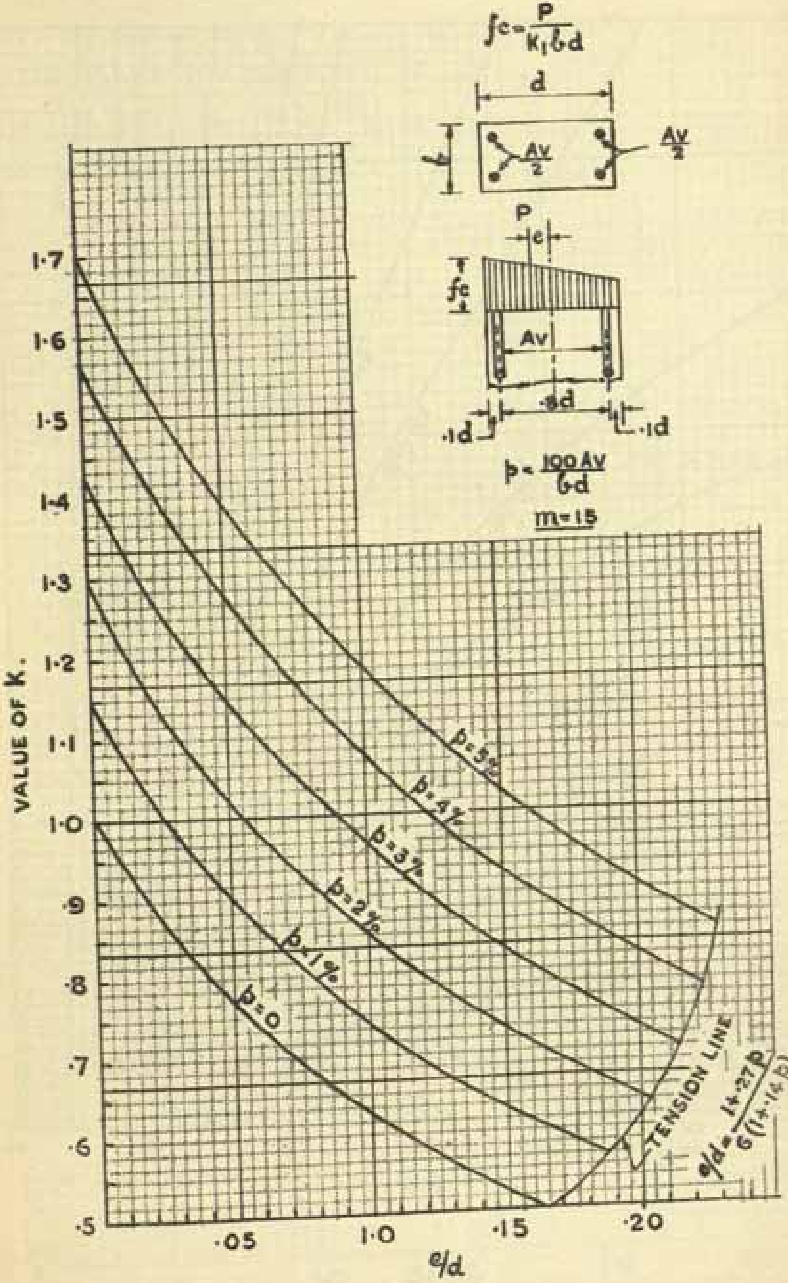


Chart 8-3

DESIGN OF COLUMNS WITH ECCENTRIC LOADS
LOCATION OF NEUTRAL AXIS.

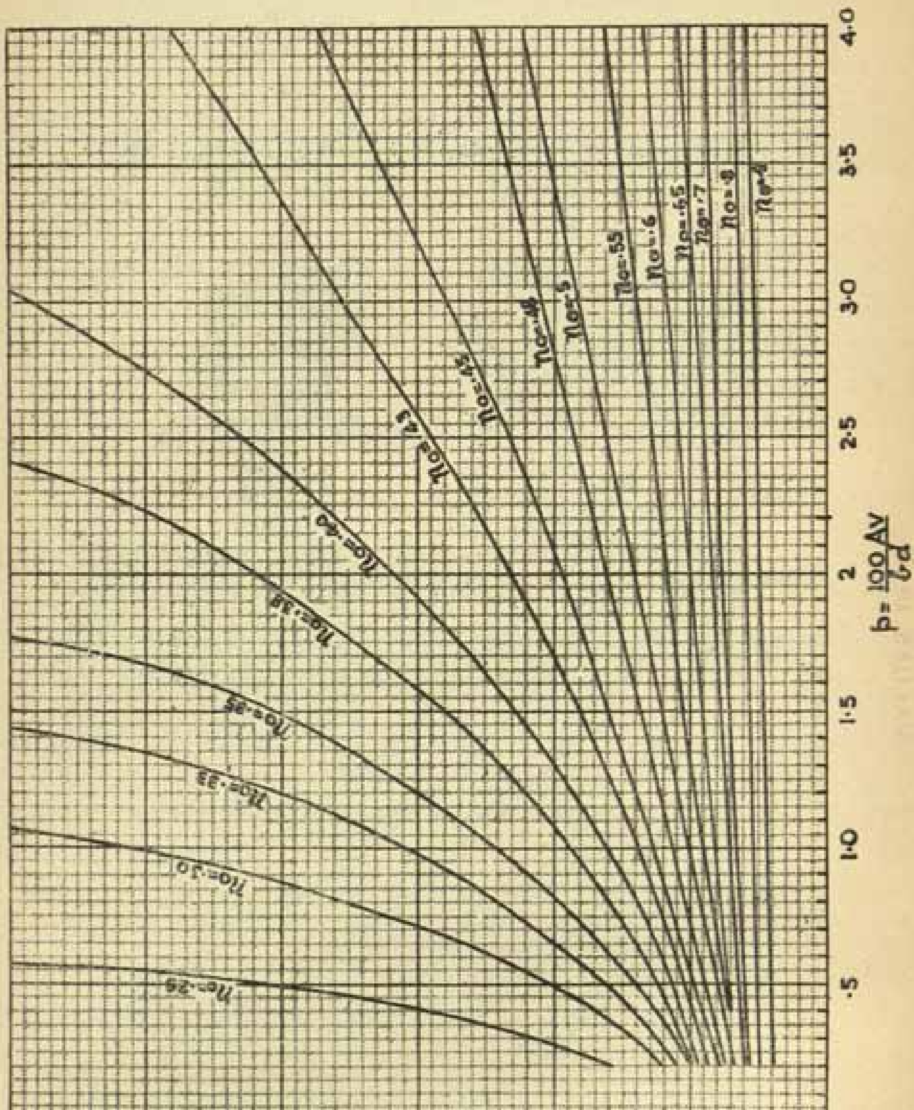
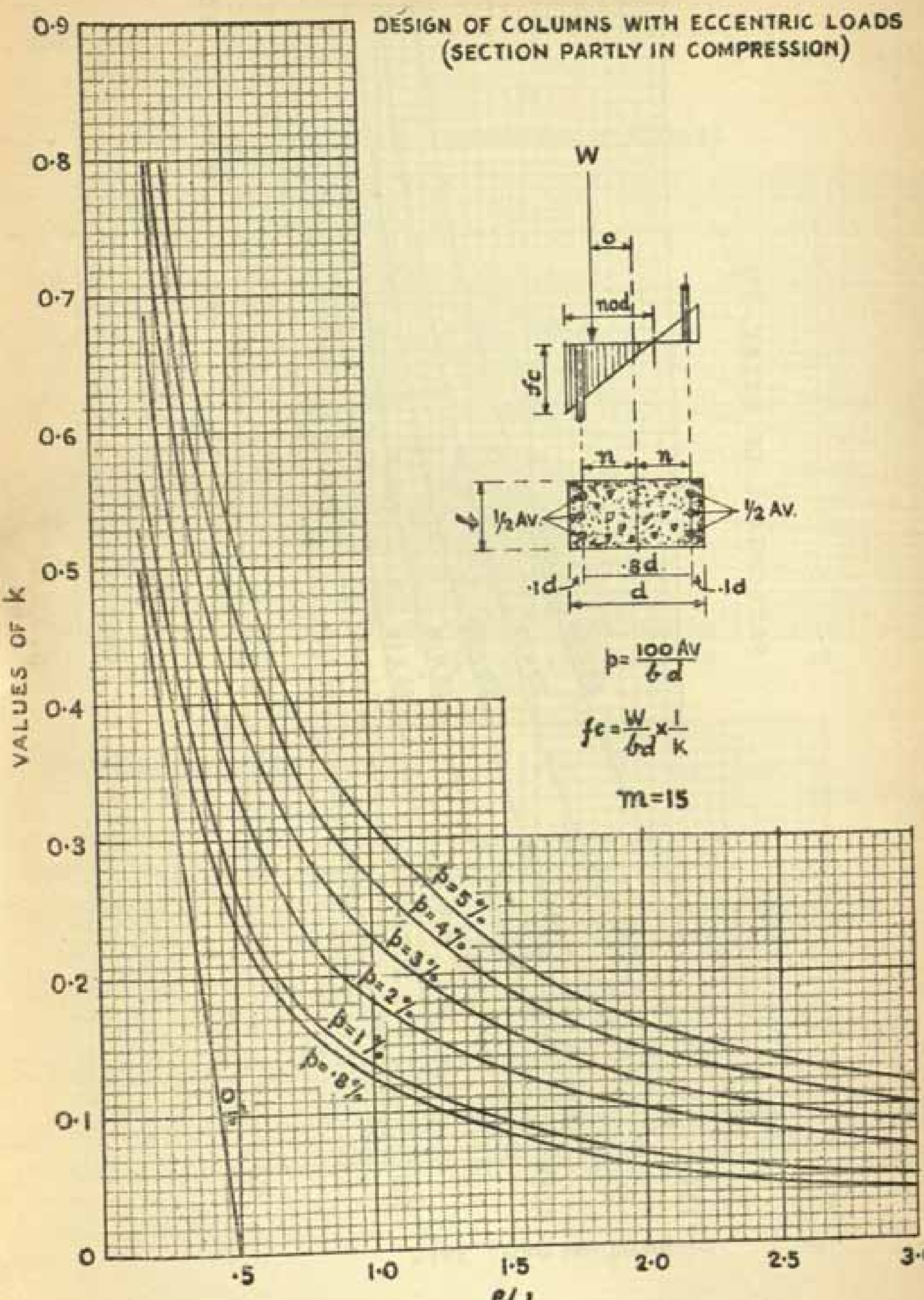


Chart 8-4



DESIGN OF COLUMNS WITH ECCENTRIC LOADS
(SECTION PARTLY IN COMPRESSION)
W
e
nod
fc
n
n
b
1/2 AV.
1/2 AV.
·8d
·1d
d
·1d
p = 100 AV / bd
fc = W/bd × 1/K
m=15
p=5%
p=4%
p=3%
p=2%
p=1%
p=·8%
0%
VALUES OF K
0·9
0·8
0·7
0·6
0·5
0·4
0·3
0·2
0·1
0
·5
1·0
1·5
2·0
2·5
3·0
e/d

Chart 8-5

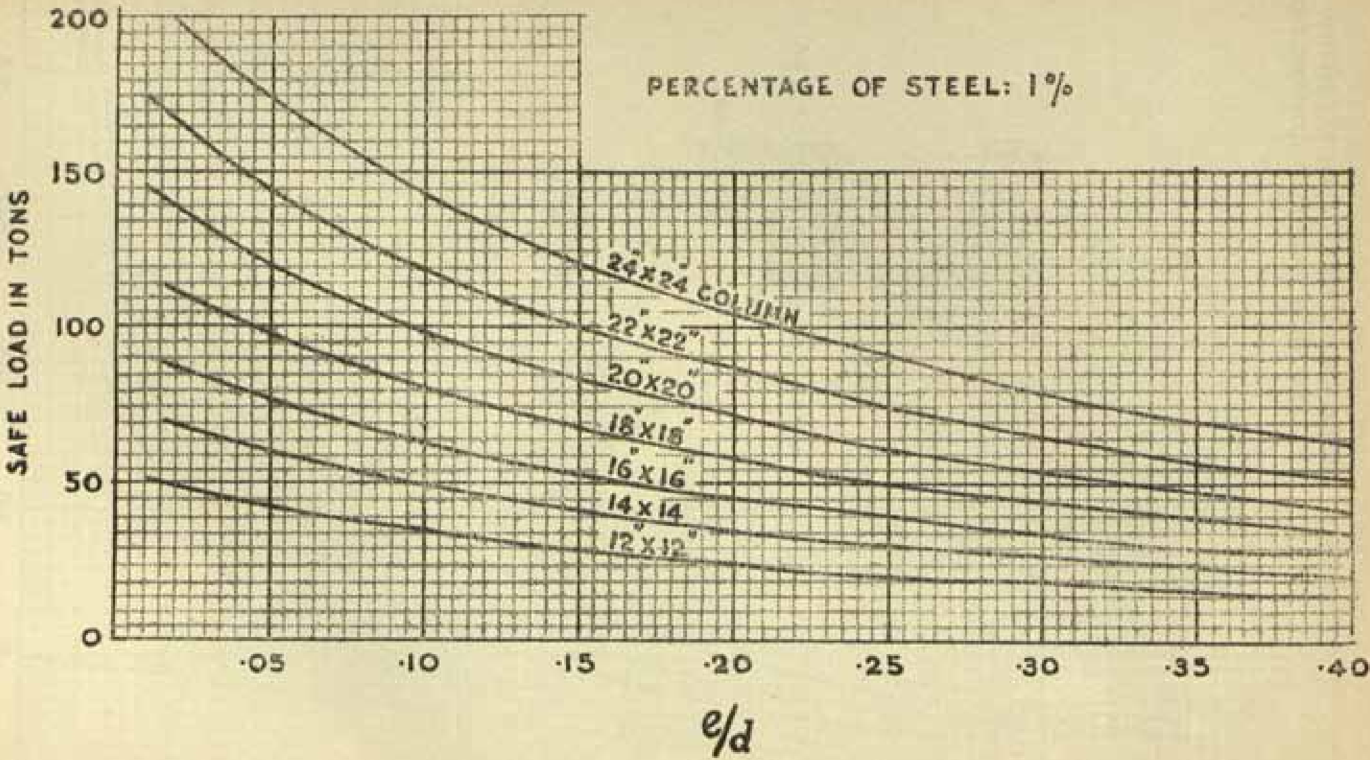

PERCENTAGE OF STEEL: 1%
SAFE LOAD IN TONS
200
150
100
50
0
·05
·10
·15
·20
·25
·30
·35
·40
24"x24" COLUMN
22"x22"
20"x20"
18"x18"
16"x16"
14"x14"
12"x12"
e/d

Chart 8-6 (a)

Chart 8-6 (b)

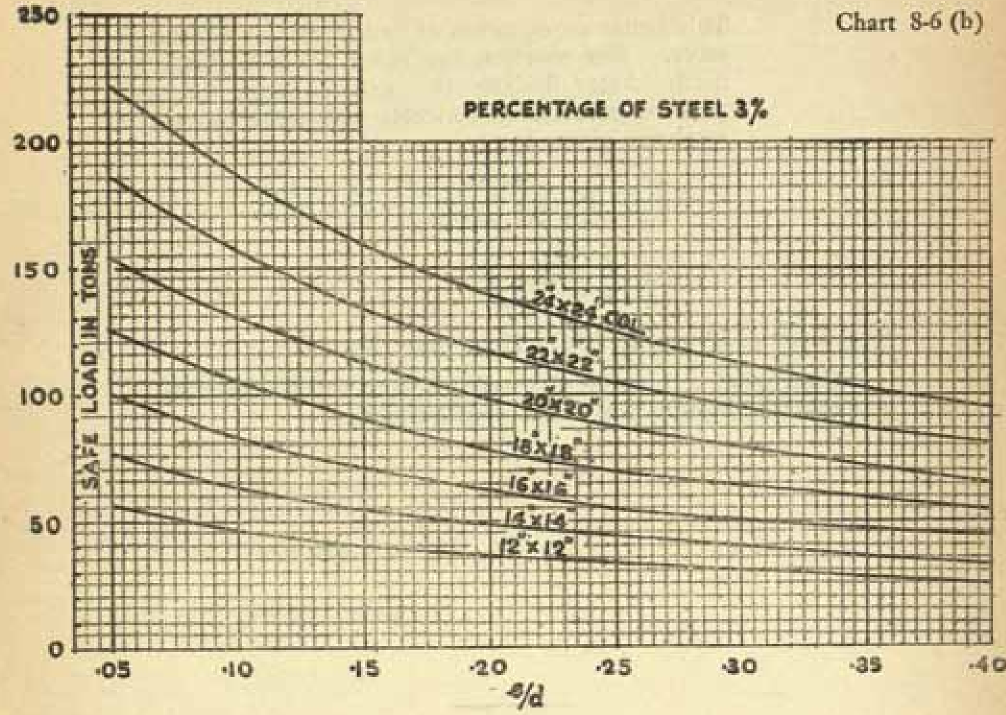
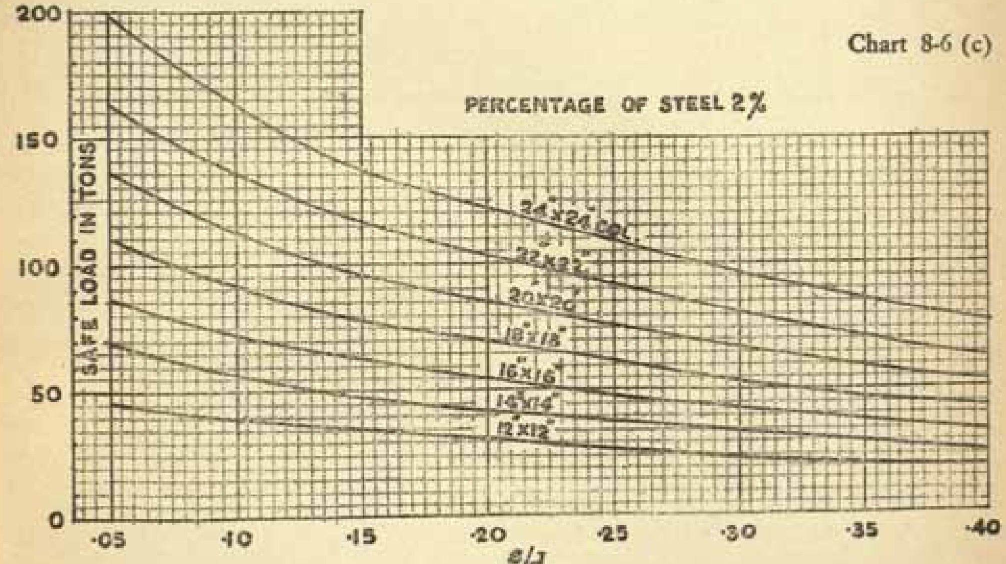


Chart 8-6 (c)



This being an equation of 3rd degree is difficult to solve. For solution the chart No. 8-4 should be used. After finding the neutral axis, the compressive stresses in concrete and tensile stress in steel are given by:

$$fc = \frac{W}{bd} \times \frac{2n_o}{n^2_o + 2mpn_o - mp} = \frac{P}{bd} \times \frac{1}{K} \text{..........(a)}$$

$$ft = mfc\left(\frac{.9}{n_o} - 1\right) \qquad \text{..........(b)}$$

the values of K can be found from chart No. 8-5.

Charts 8-6, a, b and c give safe loads on eccentrically loaded columns of different sizes and reinforcement.

CHAPTER 9

COLUMN FOOTINGS

CONTENTS

CHAPTER 9

COLUMN FOOTINGS

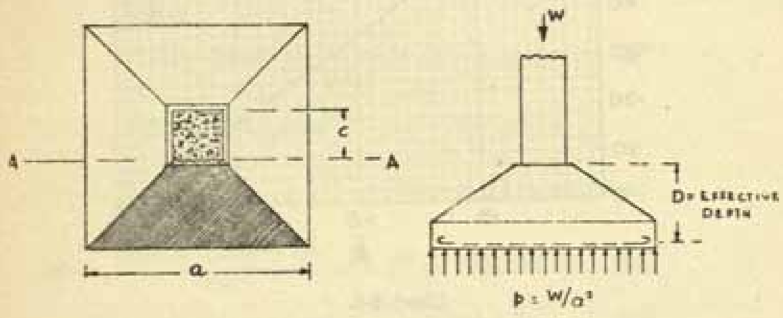
9.1 GENERAL.

Footing for a column must be safe against:

(a) Punching shear.

(b) Bending moment and shear due to soil pressure.

In addition, it must be adequately thick to allow proper embedment of the column reinforcement for complete transfer of the column load to the footing. The minimum thickness for the above condition should be 30 times the diameter of the column steel.



(a) *Punching shear*:

The perimeter of the column×depth of footing×safe punching shear=total punching force.

i.e. $4c \times D \times Sp = p(a^2 - c^2)$

Safe punching shear is taken as twice the safe ordinary shear i.e. 120 lbs./sq. inch and 150 lbs./sq. inch for Old and New L.C.C.R. respectively.

(b) *Bending moment*.

$$M = \frac{Wa}{24}\,(2 + R)\,(1 - R)^2 \text{ inch lbs.} = \frac{Wak}{24} \text{ inch lbs.}$$

where W=column load in lbs.

a=length of the side of the footing in inches.

$$R = \frac{\text{Size of column}}{\text{Size of base}}$$

This moment is at critical section AA. and is caused by soil pressure acting upwards on the hatched portion of the footing.

The values of constant k are given in chart 9-1 for various values of ratio R.

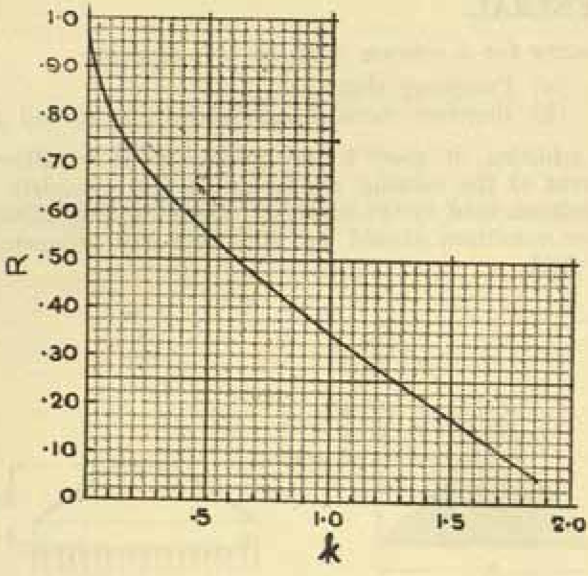


Chart 9-1.

The effective breadth of the footing is taken as

$$c+2D+\tfrac{1}{2}(a-c-2D)$$

9.2 ILLUSTRATIVE EXAMPLE.

Design r.c. footing for a column for the following conditions:—

W=load on column=126 tons

c=size of column= 21 inches

P=safe pressure on soil=3 tons/s.ft.=43.7 lbs./sq. in.

Sp=safe punching stress=150 lbs./sq. in.

Diameter of column reinforcement=1″.

(a) Size of footing:

total load on soil $=126$ tons$+$say 10% wt. of footing $=140$ tons approximately.

$$\text{size of footing} = \sqrt{\frac{140}{3}} = 6.82 \text{ ft.} = 7'\text{-}0'' \text{ say}$$
$$= 84'' = a$$

(b) Depth for safe punching stress.

$4c \times D \times Sp = p(a^2 - c^2)$

$84 \times D \times 150 = 43.7(84^2 - 21^2)$

$D = 23''$

Take total depth of footing as 30″, the column bars being 1″ ϕ

(The effective depth may be taken as 27″)

(c) Bending moment.

$R = \frac{21}{84} = .25$ $\qquad$ $k = 1.27$ from graph

$$M = \frac{(126 \times 2240) \times 84}{24} \times 1.27 = 1250000 \text{ inch lbs.}$$

effective width of footing $= c + 2D + \frac{1}{2}(a - c - 2D)$

$= 21 + 54 + \frac{1}{2}(84 - 21 - 54)$

$= 79\frac{1}{2}'' = 80$ inches.

$$d \text{ for B.M} = \sqrt{\frac{1250000}{126 \times 80}} = 11.5''$$

$$A_T = \frac{1250000}{18000 \times .87 \times 27} = 3 \text{ sq. inches.}$$

use 10 Nos $\frac{5}{8}''$ ϕ bars both ways.

Details of column footings for columns in Chapter 8 are given in Tables 9 (a) and 9 (b).

9.3 DESIGN TABLES.

Table 9-a
SQUARE FOOTINGS
(fc=750 lbs./□″ fs=18000 lbs./□″ m=15)

Ref No. of Column	½ Ton/□Ft.					1 Ton/□Ft.				
	a	D	Concrete C.Ft.	Steel Bars	Steel Lbs.	a	D	Concrete C.Ft.	Steel Bars	Steel Lbs.
C1a	5′-0″	13″	20·85	6 5/8″	26	3′-7″	13″	11·0	5 5/8″	16
C2a	6′-6″	14″	36·10	10 5/8″	55	4′-6″	14″	17·88	8 5/8″	32
C2b	7′-0″	18″	48·44	9 5/8″	51	5′-0″	18″	25·50	8 5/8″	30
C3a	7′-6″	14″	47·77	14 5/8″	87	5′-3″	14″	24·10	10 5/8″	46
C3b	7′-9″	18″	59·22	13 5/8″	84	5′-6″	18″	30·82	9 5/8″	42
C3c	8′-0″	21″	68·89	13 5/8″	86	5′-9″	21″	36·70	8 5/8″	40
C4a	8′-3″	15″	59·61	11 1/2″	132	5′-9″	15″	30·27	14 5/8″	70
C4b	8′-4″	18″	68·89	17 5/8″	106	6′-0″	18″	39·90	11 5/8″	56
C4c	8′-9″	21″	82·80	16 5/8″	106	6′-3″	21″	43·68	11 5/8″	58
C4d	8′-9″	24″	89·92	14 5/8″	101	6′-3″	24″	47·50	9 5/8″	45
C5a	9′-9″	21″	103·43	13 1/2″	182	7′-0″	21″	55·38	10 1/2″	106
C5b	10′-0″	21″	108·62	14 1/2″	202	7′-0″	21″	55·38	9 1/2″	96
C5c	10′-3″	24″	123·64	18 5/8″	412	7′-3″	24″	64·39	12 5/8″	73
C5d	10′-6″	24″	129·54	15 1/2″	226	7′-6″	24″	68·61	10 1/2″	110
C6a	11′-6″	21″	143·23	22 1/2″	362	8′-3″	21″	76·23	14 1/2″	169
C6b	11′-6″	27″	167·90	16 1/2″	262	8′-3″	27″	89·74	12 1/2″	114
C6c	12′-0″	27″	182·00	12 3/4″	318	8′-6″	27″	95·00	13 1/2″	160
C7a	12′-6″	21″	168·60	18 5/8″	496	8′-9″	21″	85·66	12 5/8″	237
C7b	12′-9″	24″	190·12	16 5/8″	450	9′-0″	24″	98·27	11 5/8″	229
C7c	13′-0″	24″	197·37	17 5/8″	486	9′-3″	24″	103·42	12 5/8″	229
C8a	13′-3″	24″	205·64	18 5/8″	524	9′-3″	24″	104·21	12 5/8″	229
C8b	13′-6″	24″	213·09	14 3/4″	600	9′-6″	24″	109·50	14 5/8″	306
C8c	13′-9″	24″	220·68	14 3/4″	609	9′-9″	24″	114·93	15 5/8″	335
C9a	14′-6″	27″	265·67	15 3/4″	686	10′-6″	27″	144·52	15 5/8″	370
C9b	14′-9″	27″	274·44	16 3/4″	744	10′-6″	27″	144·52	15 5/8″	370
C9c	15′-0″	27″	283·44	16 3/4″	756	10′-6″	27″	144·52	12 3/4″	414
C10a	16′-6″	30″	370·59	17 3/4″	880	11′-9″	30″	195·00	16 3/4″	624

Note: See Table 8-a Chapter No. 8 for Column Reference Number.

Table 9-a (contd.)
SQUARE FOOTINGS

(fc=750 lbs./□″ fs=18000 lbs./□″ m=15)

Ref. No. of Column	2 Tons/□Ft.					4 Tons/□Ft.				
	a	D	Concrete C.Ft.	Steel Bars	Steel Lbs.	a	D	Concrete C.Ft.	Steel Bars	Steel Lbs.
C1a	2′-6″	13″	5·56	5 5/8″	12	2′-0″	13″	3·72	5 5/8″	10
C1a	3′-3″	14″	9·72	8 5/8″	24	2′-3″	14″	4·98	8 5/8″	18
C2b	3′-6″	18″	13·12	7 5/8″	23	2′-6″	18″	7·12	7 5/8″	17
C3a	3′-9″	14″	12·77	10 5/8″	34	2′-8″	18″	8·12	10 5/8″	27
C3b	3′-9″	18″	15·07	9 5/8″	31	2′-9″	18″	8·70	9 5/8″	24
C3c	4′-0″	21″	18·75	8 5/8″	30	3′-0″	21″	11·21	8 5/8″	23
C4a	4′-0″	15″	15·50	11 5/8″	40	3′-0″	15″	9·22	11 5/8″	31
C4b	4′-3″	18″	19·44	11 5/8″	42	3′-0″	18″	10·50	11 5/8″	31
C4c	4′-4″	21″	20·23	10 5/8″	38	3′-0″	21″	11·56	10 5/8″	29
C4d	4′-6″	24″	25·98	8 5/8″	30	3′-3″	24″	14·66	8 5/8″	24
C5a	5′-0″	21″	29·87	12 5/8″	52	3′-6″	21″	15·89	12 5/8″	39
C5b	5′-0″	21″	29·87	13 5/8″	57	3′-6″	21″	15·47	13 5/8″	42
C5c	5′-3″	24″	35·64	12 5/8″	54	3′-9″	24″	19·68	12 5/8″	41
C5d	5′-3″	24″	35·64	12 5/8″	54	3′-9″	24″	19·68	12 5/8″	41
C6a	5′-9″	21″	39·15	16 5/8″	79	4′-0″	21″	20·70	16 5/8″	58
C6b	6′-0″	24″	46·26	15 5/8″	79	4′-3″	21″	22·95	17 5/8″	65
C6c	6′-0″	24″	46·26	15 5/8″	79	4′-3″	21″	22·95	18 5/8″	68
C7a	6′-3″	21″	45·95	8 5/8″	116	4′-5″	21″	24·65	18 5/8″	72
C7b	6′-6″	21″	49·39	13 1/2″	126	4′-6″	21″	25·62	13 1/2″	91
C7c	6′-6″	24″	53·92	14 1/2″	136	4′-9″	24″	30·88	14 1/2″	103
C8a	6′-6″	21″	49·87	22 5/8″	122	4′-9″	21″	28·58	22 5/8″	91
C8b	6′-9″	24″	58·33	15 1/2″	150	4′-9″	24″	31·28	15 1/2″	111
C8c	6′-10″	24″	59·72	16 1/2″	164	4′-10″	24″	32·38	16 1/2″	120
C9a	7′-3″	24″	67·46	18 1/2″	102	5′-3″	24″	38·14	18 1/2″	144
C9b	7′-6″	27″	77·79	16 1/2″	177	5′-3″	27″	41·50	16 1/2″	128
C9c	7′-3″	27″	73·14	17 1/2″	182	5′-0″	27″	38·24	17 1/2″	132
C10a	8′-3″	27″	93·81	21 5/8″	393	5′-10″	27″	50·89	21 5/8″	304

Note: See Table 8-a Chapter No. 8 for Column Reference Number.

Table 9-b
SQUARE FOOTINGS

(fc=600 lbs./□" fs=16000 lbs./□" m=15.)

Ref No. of Column	½ Ton/□Ft.					1 Ton/□F.				
	a	D	Concrete C.Ft.	Steel Bars	Steel Lbs.	a	D	Concrete C.Ft.	Steel Bars	Steel Lbs.
C1	4'-9"	12"	18·38	7 ⅝"	28·00	3'-4"	12"	9·50	5 ⅝"	15·0
C2	5'-5"	12"	24·12	9 ⅝"	40·50	3'-9"	12"	12·1	6 ⅝"	19·50
C3a	5'-10"	12"	27·70	12 ⅝"	57·00	4'-3"	12"	15·4	10 ⅝"	35·6
C3b	6'-4"	15"	36·54	11 ⅝"	58·00	4'-6"	15"	19·3	8 ⅝"	30·0
C4a	7'-6"	15"	51·37	13 ½"	120·0	5'-3"	15"	26·4	12 ⅝"	51·8
C4b	8'-0"	18"	64·60	13 ½"	128·0	5'-6"	18"	32·1	8 ½"	64·0
C4c	8'-2"	21"	74·50	13 ½"	130·0	5'-9"	21"	38·5	8 ½"	67·6
C5a	9'-0"	18"	80·60	12 ⅝"	235·0	6'-3"	18"	40·7	10 ½"	90·0
C5b	9'-4"	18"	86·57	12 ⅝"	245·0	6'-6"	18"	43·7	10 ½"	94·0
C5c	9'-6"	21"	98·50	13 ⅝"	279·4"	6'-9"	21"	56·7	8 ⅝"	108·2
C5d	9'-9"	21"	103·53	12 ⅝"	282·00	7'-0"	24"	60·4	10 ½"	100·0
C6a	10'-0"	18"	100·23	13 ⅝"	279·38	7'-0"	18"	51·3	9 ⅝"	148·6
C6b	10'-4"	21"	117·27	13 ⅝"	288·5	7'-4"	21"	61·7	13 ½"	139·0
C6c	10'-6"	24"	131·96	12 ⅝"	252·3	7'-6"	24"	70·4	12 ½"	128·0
C7a	10'-9"	18"	115·08	18 ⅝"	368·6	7'-6"	18"	58·3	11 ⅝"	190·7
C7b	10'-10"	21"	128·29	16 ⅝"	325·7	7'-8"	21"	66·9	10 ⅝"	176·6
C7c	11'-6"	24"	156·77	16 ⅝"	343·8	8'-0"	24"	79·3	10 ⅝"	183·7
C7d	11'-6"	27"	169·74	15 ⅝"	318·2	8'-0"	27"	86·0	10 ⅝"	183·7
C8a	12'-6"	21"	170·75	17 ¾"	688·5	8'-9"	21"	87·3	13 ⅝"	259·0
C8b	12'-6"	24"	186·20	15 ¾"	607·5	9'-0"	24"	100·6	13 ⅝"	267·0
C8c	13'-0"	27"	217·16	15 ¾"	630·0	9'-2"	27"	113·0	12 ⅝"	247·6
C8d	14'-0"	27"	250·00	15 ¾"	667·5	10'-0"	27"	132·7	12 ⅝"	270·4
C9a	14'-0"	24"	234·00	16 ⅞"	968·3	10'-0"	24"	123·3	16 ⅝"	360·5
C9b	14'-3"	27"	258·57	15 ⅞"	938·4	10'-0"	27"	132·7	16 ⅝"	360·5
C9c	14'-6"	24"	247·00	17 ⅞"	1075·0	10'-4"	24"	130·0	13 ¾"	448·5
C9d	15'-0"	24"	263·70	18 ⅞"	1175·0	10'-6"	24"	134·0	14 ¾"	483·0

Note: See Table 8-b Chapter No. 8 for Column, Reference Numbers.

Table 9-b (contd.)
SQUARE FOOTINGS

(fc=600 lbs./□″ fs=16000 lbs./□″ m=15.)

Ref. No. of Column	2 Tons/□Ft.					4 Tons/□Ft.				
	a	D	Concrete C.Ft.	Steel Bars	Lbs.	a	D	Concrete C.Ft.	Steel Bars	Lbs.
C1	2′-6″	12″	5·57	6 ⅝″	13·50	1′-9″	12″	2·98	6 ⅝″	10·5
C2	2′-9″	12″	6·9	6 ⅝″	14·62	2′-0″	12″	3·98	6 ⅝″	11·25
C3a	3′-0″	12″	8·1	7 ⅝″	18·37	2′-2″	12″	4·60	7 ⅝″	14·40
C3b	3′-3″	15″	10·7	6 ⅝″	16·87	2′-4″	15″	6·00	6 ⅝″	13·50
C4a	3′9″	15″	14·3	9 ⅝″	28·70	2′-9″	15″	8·42	9 ⅝″	21·93
C4b	4′-0″	18″	18·10	8 ⅝″	21·10	2′-10″	18″	10·00	8 ⅝″	21·00
C4c	4′-2″	21″	21·63	8 ⅝″	21·37	3′-0″	21″	12·37	8 ⅝″	21·50
C5a	4′-6″					3′-3″	18″	12·62	10 ⅝″	28·75
C5b	4′-9″					3′-4″	18″	13·18	11 ⅝″	32·31
C5c	4′-10″	21″	28·1	9 ½″	66·0	3′-6″	21″	16·00	9 ½″	48·00
C5d	5′-0″	24″	32·8	8 ⅝″	32·25	3′-6″	24″	17·65	8 ⅝″	24·00
C6a	5′-0″	18″	27·8	9 ½″	67·00	3′-6″	18″	15·05	9 ½″	48·00
C6b	5′-3″	21″	33·7	10 ½″	77·80	3′-8″	21″	18·81	12 ⅝″	38·25
C6c	5′-4″	24″	38·0	10 ⅝″	44·70	3′-9″	24″	20·84	10 ⅝″	32·50
C7a	5′-6″	18″	33·0	12 ½″	97·93	3′-9″	18″	16·90	12 ½″	69·33
C7b	5′-6″	21″	36·6	10 ½″	81·11	3′-10″	21″	19·55	10 ½″	58·88
C7c	5′-9″	24″	43·5	9 ½″	76·00	4′-0″	24″	23·20	9 ½″	55·00
C7d	5′-9″	27″	47·3	9 ½″	76·00	4′-2″	27″	27·20	9 ½″	57·00
C8a	6′-3″	21″	47·4	12 ½″	109·3	4′-4″	21″	25·10	12 ½″	78·66
C8b	6′-4″	24″	53·1	11 ½″	101·5	4′-6″	24″	29·52	11 ½″	74·55
C8c	6′-6″	27″	60·6	12 ½″	113·3	4′-9″	27″	35·62	12 ½″	85·33
C8d	6′-6″	27″	60·6	12 ½″	113·3	5′-0″	27″	38·50	12 ½″	89·33
C9a	7′-0″	24″	63·6	12 ⅝″	195·5	5′-0″	24″	35·25	12 ⅝″	145·60
C9b	7′-0″	27″	69·2	12 ⅝″	195·5	5′-0″	27″	38·50	12 ⅝″	145·60
C9c	7′-4″	24″	69·1	12 ⅝″	203·8	5′-2″	24″	37·32	12 ⅝″	149·8
C9d	7′-6″	24″	72·0	12 ⅝″	208·0	5′-4″	24″	39·34	12 ⅝″	153·9

Note: See Table 8-b Chapter No. 8 for Column, Reference Numbers.

CHAPTER 10

RETAINING WALLS

CONTENTS

CHAPTER 10

RETAINING WALLS

10.1 SMALL RETAINING WALLS.

Small retaining walls upto 15′–0″ are mostly of cantilever type. Retained materials like sand, gravel, earth, etc. exert on the retaining structure pressure of much the same nature as ordinary fluids. The intensity of this pressure (we) depends upon the weight (w), angle of repose (ϕ) and angle of surcharge (α) of the material and is given by the formula.

$$we = w \cos\alpha \frac{\cos\alpha - \sqrt{\cos^2\alpha - \cos^2\phi}}{\cos\alpha + \sqrt{\cos^2\alpha - \cos^2\phi}} = wk.$$

when there is no surcharge i.e. when $\alpha = 0$. This reduces to

$$we = w\,\frac{1 - \sin\phi}{1 + \sin\phi} = wk$$

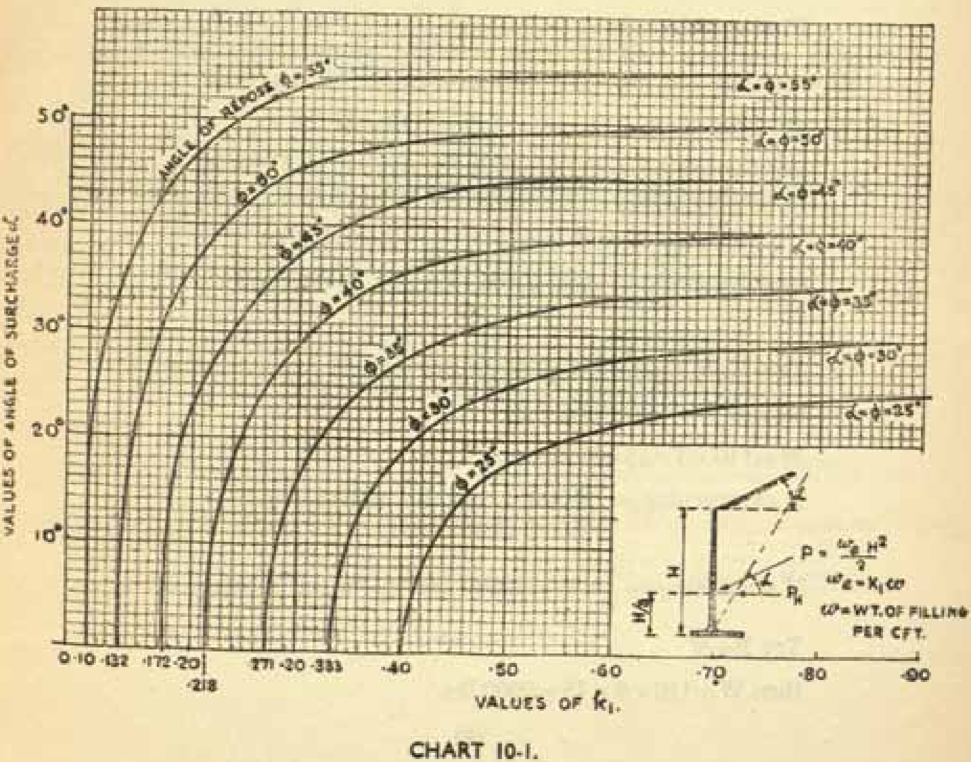


CHART 10-1.

Chart No. 10-1 gives the values of k for different values of ϕ and α and Table No. 10-a gives the values w and ϕ for various filling materials.

In case of a cantilevered retaining wall it is necessary to see that:

(a) the stem, heel and toe are adequately reinforced for B.M. and shear

(b) the overturning moment is less than the stabilizing moment

(c) the pressure on the ground is within safe limits

(d) the wall is safe against sliding

Charts 10-2 to 10-6 may be used with advantage for preliminary designs which can subsequently be modified slightly by exact calculations.

10.2 EXAMPLE.

Find approximate dimensions and reinforcement for a cantilever retaining wall 12′ high over the ground level with level fill weighing 110 lbs./c.ft. and with angle of repose of 30°.

we, from chart 10-1 $=$ $.33\times110=37$ lbs.

overturning force P (from chart 10-3) $\left.\right\} =$ 4500 for we$=40$ and H$=15$; 3700 for we$=30$ and H$=15$

$\therefore$ for we$=37$ and H$=15$ P$=4170$ lbs.

effective depth of stem (from chart 10-2) for H$=14'-0''$

$=13''$

and $A_T=1.25\square''$ i.e. $\frac{3}{4}''$ ϕ @ $4''$ c.c. for we$=37$ (by interpolation)

assume $B=.5\times15=7\frac{1}{2}$ ft.

$W=110\times5\times15=8250$ lbs.

M overturning $=$ 21200 ft. lbs. (by interpolation) (from chart 10-4)

M stabilizing $=\frac{5}{2}\times W=20500$ lbs. ft. (factor of safety 2)

Try $B=9'$

then $W=110\times6\times15=9900$ lbs.

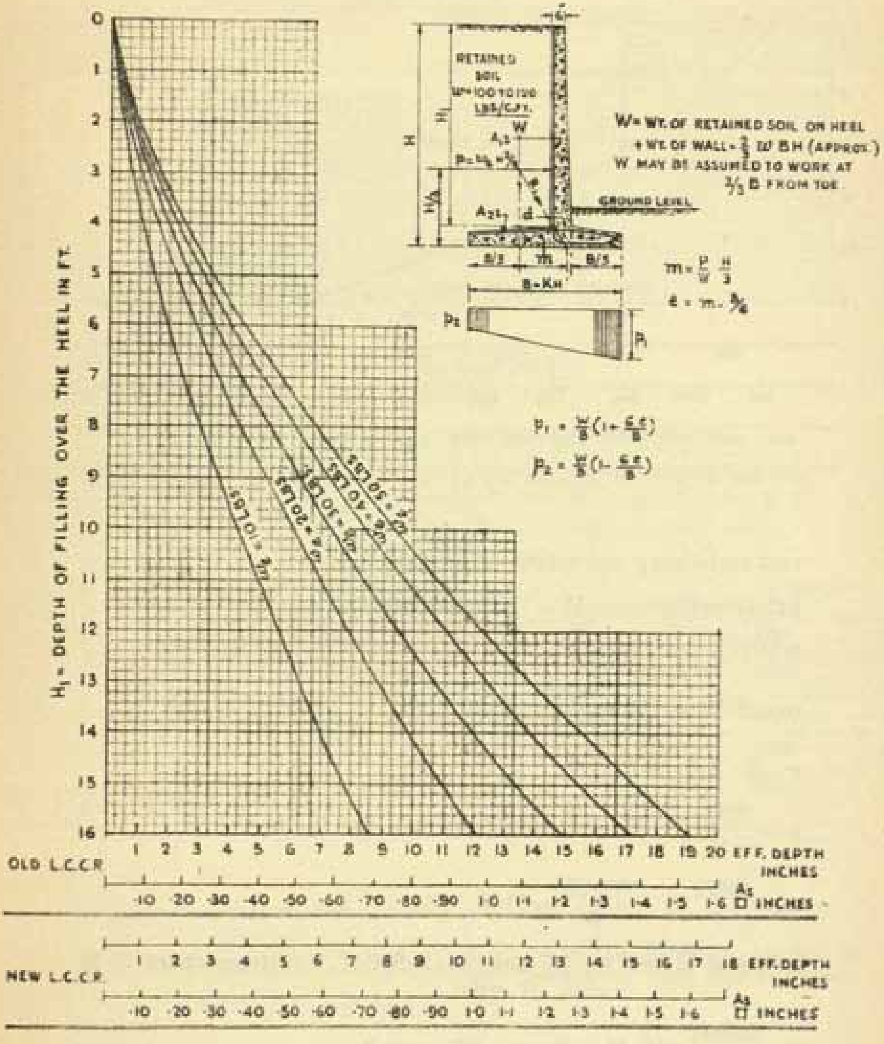
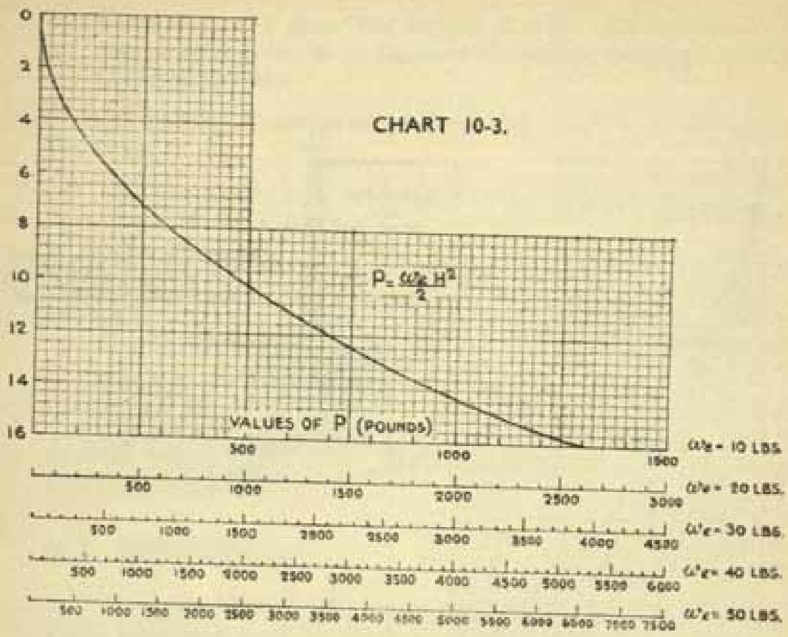

RETAINED SOIL
w = 100 TO 120 LBS/C.FT.
W = WT. OF RETAINED SOIL ON HEEL + WT. OF WALL = $\frac{2}{3}$ w BH (APPROX.)
W MAY BE ASSUMED TO WORK AT 2/3 B FROM TOE
GROUND LEVEL
B = KH
m = $\frac{P}{W}\cdot\frac{H}{3}$
e = m. B/6
$p_1 = \frac{W}{B}(1+\frac{6e}{B})$
$p_2 = \frac{W}{B}(1-\frac{6e}{B})$
H_1 = DEPTH OF FILLING OVER THE HEEL IN FT.
OLD L.C.C.R.
EFF. DEPTH INCHES
A_s □ INCHES
NEW L.C.C.R.
EFF. DEPTH INCHES
A_s □ INCHES

Chart 10-2.



and stabilizing mt $= 9900 \times 3 = 29700$ ft. lbs.

Frictional force $= \mu W = .7 \times 9900 = 6930$ lbs.

which is more than P.

$$m = P/W \times H/3 = \frac{4170}{9900} \times 5 = 2.1 \text{ ft.}$$

$$e = 3 + 2.1 - 9/2 = .6$$

$$p_1 = \frac{9900}{9}\left(1 + \frac{6 \times .6}{9}\right) = 1100 \times 1.4 = 1540 \text{ lbs/ft.}$$

$$p_2 = \frac{9900}{9}\left(1 - \frac{6 \times .6}{9}\right) = 1100 \times .6 = 660 \text{ lbs./ft.}$$

moment in heel for 15′ height $= 20500$ ft. lbs. (from chart 10-5)
and 5′ span

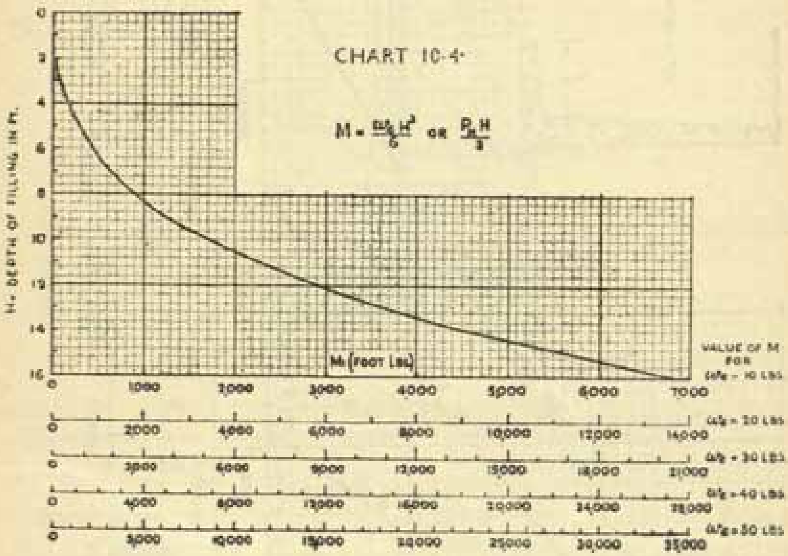
$$d = \frac{20500}{126} = 12.7'' \text{ max. say } 15'' \text{ overall.}$$

$$A_T = \frac{20500}{18000 \times .87 \times 12.7} = 1.05''$$

$$\text{moment in toe} = \frac{1540 \times 3^2}{2} = 6900 \text{ ft. lbs.}$$

$$\text{A}_T \text{ for } 15\tfrac{1}{2}'' \text{ depth} = \frac{6900 \times 12}{18000 \times .87 \times 15.5}$$

$$= .34\square'' \text{ i.e. } \tfrac{5}{8}''\phi \text{ @ } 10''$$



Note:

The above chart gives the Bending Moment caused in the vertical member of a cantilever retaining wall due to different values of earth pressure.

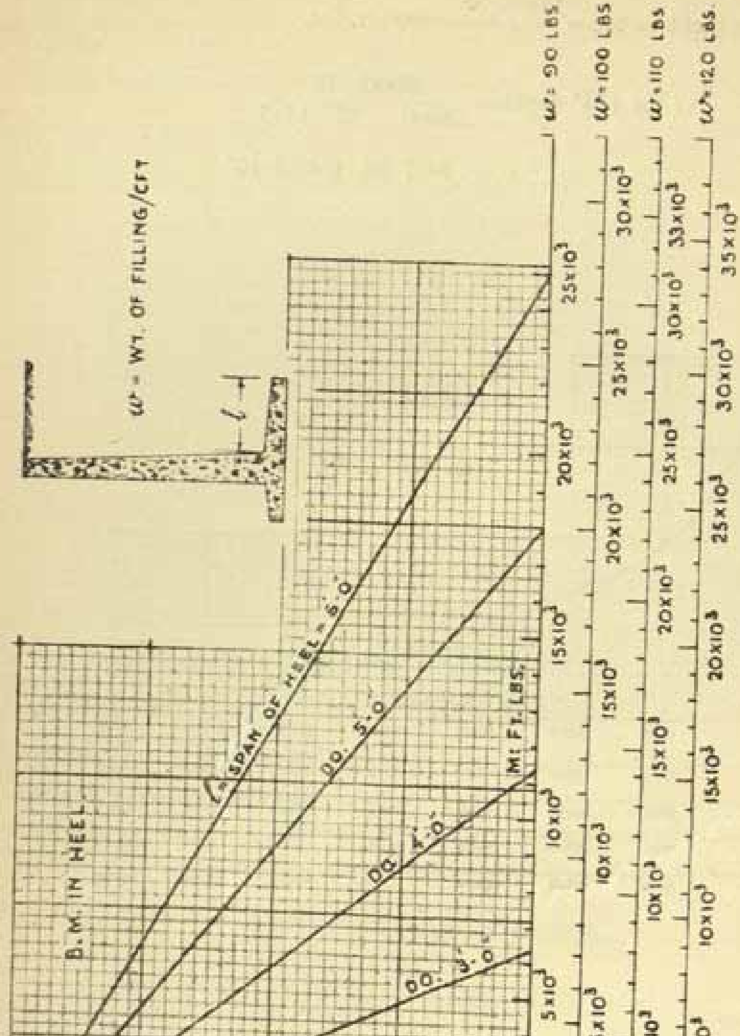

B.M. IN HEEL
w = WT. OF FILLING/CFT
l
l = SPAN OF HEEL = 6'.0"
DO. 5'.0"
DO. 4'.0"
DO. 3'.0"
DO. 2'.0"
M: FT. LBS.
w = 90 LBS
w = 100 LBS
w = 110 LBS
w = 120 LBS
H = DEPTH OF FILLING IN FT.

CHART 10-5.

From these approximate details accurate calculation in which W includes the weight of wall, and in which the point of application of W etc. is correctly calculated can be carried out, and final details worked out accurately.

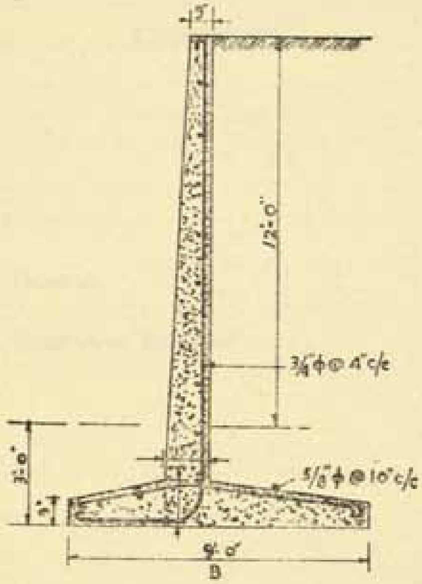


Table 10-a

Material	w (lbs/cft.)	φ(degrees)
Sand dry	90 to 100	30
,, moist	100 to 110	35
,, wet	110 to 125	25
Vegetable earth dry	90 to 100	30
-do- moist	100 to 110	45
-do- wet	110 to 120	15
Gravel	90	40
Rubble stone	100 to 110	45
Gravel & Sand	100 to 110	25 to 30
Clay dry	120 to 140	30
,, moist	120 to 160	45
,, wet	120 to 160	15
,, mud	105 to 120	0
Ashes	40	40

CHAPTER 11

CIRCULAR TANKS

CONTENTS

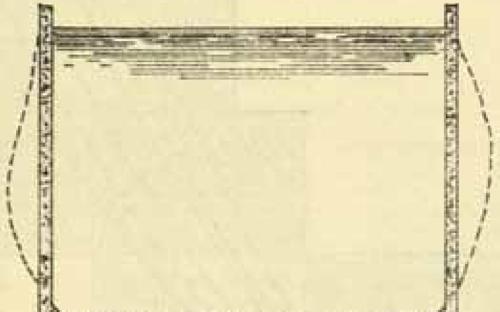
CHAPTER 11

CIRCULAR TANKS

11.1 GENERAL.

The pressure of water at a depth of h ft. is 62.5 h lbs. per sq.ft. In case of a circular tank the tension in the tank walls caused by the water pressure is therefore $\frac{62.5hD}{2}$ lbs. in a ring one foot high, of diameter D ft. and situated at a mean depth of h ft. below the surface. The cross sectional area of steel rings to be provided in this strip is $\frac{62.5hD}{2 \times 12000}$ sq. inches.

The walls of all tanks are, however, restrained at the base being monolythic with the floor and the walls assume the shape shown in sketch below when the tank is filled with water.



Deflection of Tank Walls.

In such a case the water pressure at the bottom is entirely resisted by the cantilever action of the vertical wall which is subjected to tensile stress on the inner face. In case of shallow tanks of large diameter, the tendency of the walls is to act more

like vertical cantilevers and hoop stresses are small, whereas in cases of deep tanks of small diameter, hoop stresses are more and cantilever action is very small.

The enclosed charts give

(a) Capacity of tanks in gallons for various heights and diameters (Chart No. 11-1).

(b) Position of maximum hoop tension (Chart No. 11-2).

(c) Amount of maximum hoop tension (Chart No. 11-3).

(d) Amount of restraint moment (Chart No. 11-4).

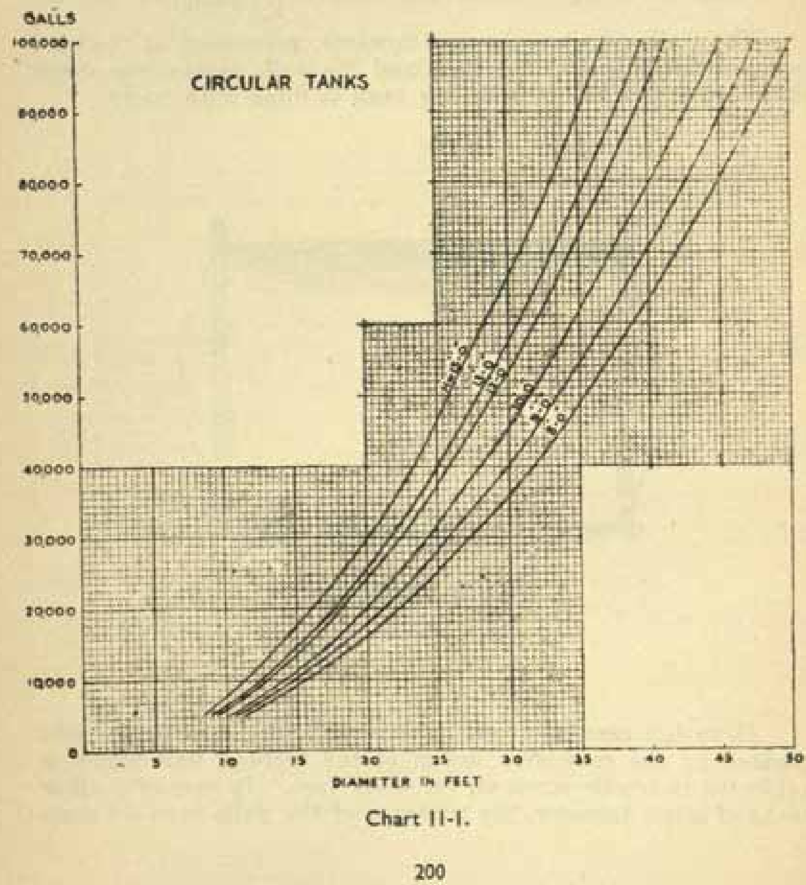


Chart 11-1.

CYLINDRICAL TANKS

POSITION OF MAX. HOOP TENSION.

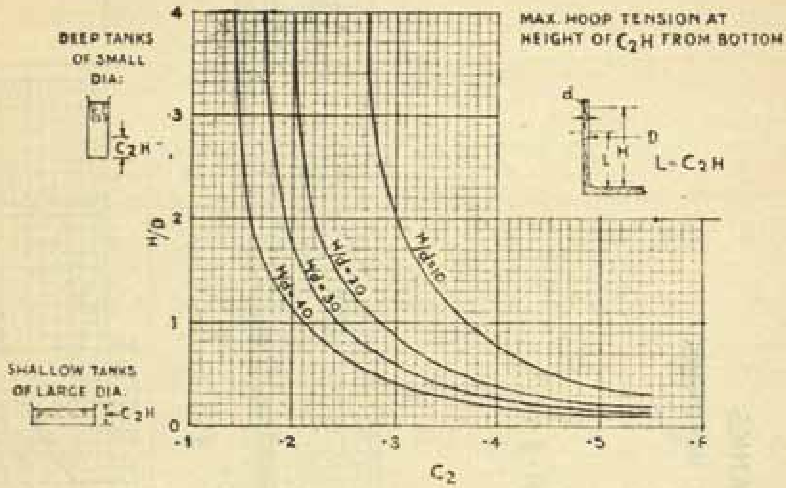


Chart 11-2.

CYLINDRICAL TANKS

AMOUNT OF MAXIMUM HOOP TENSION

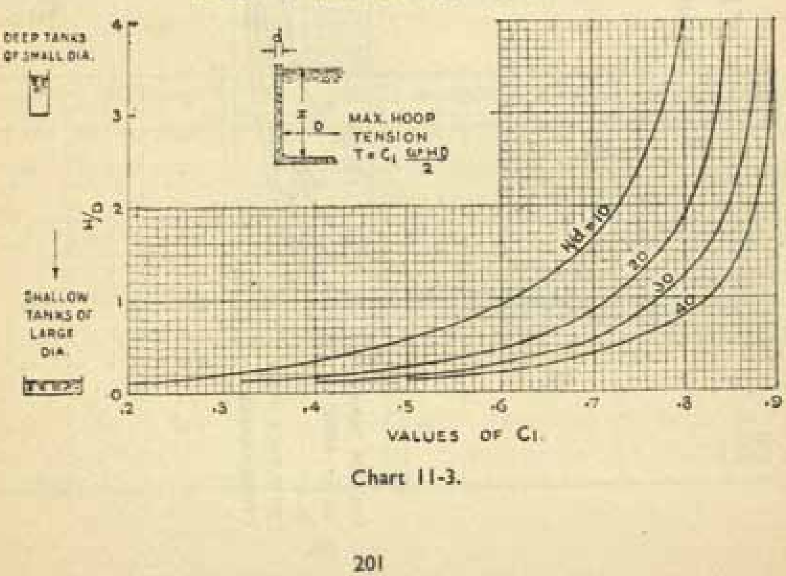


Chart 11-3.

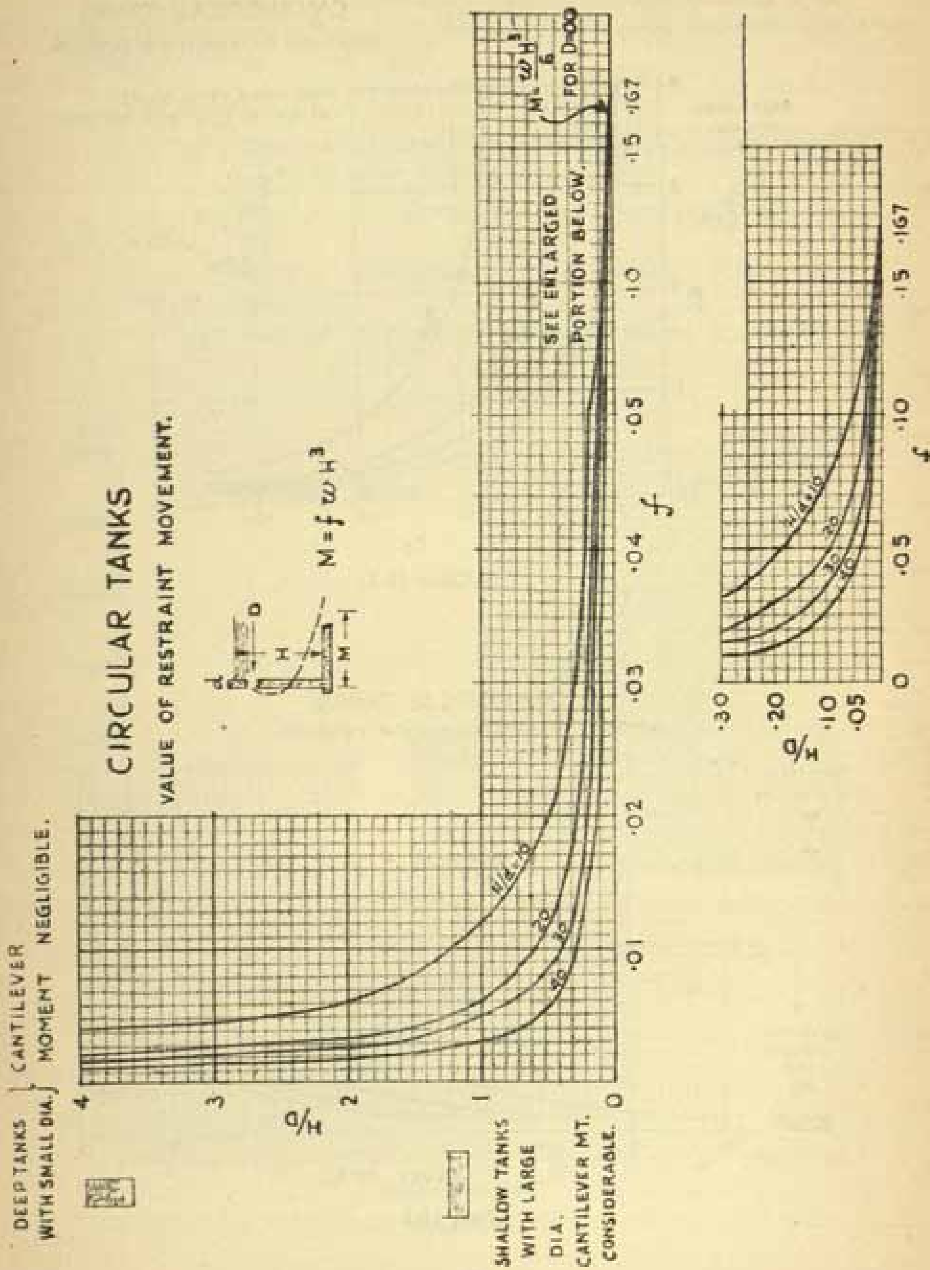

CIRCULAR TANKS
VALUE OF RESTRAINT MOVEMENT.
M = f ω H³
DEEP TANKS WITH SMALL DIA.
CANTILEVER MOMENT NEGLIGIBLE.
SHALLOW TANKS WITH LARGE DIA.
CANTILEVER MT. CONSIDERABLE.
SEE ENLARGED PORTION BELOW.
M = ωH³/6 FOR D=∞
D/H
f
H/d=10
20
30
40
4
3
2
1
0
·01
·02
·03
·04
·05
·10
·15
·167
·30
·20
·10
·05

Chart 11-4.

Table 11-a gives detail of tanks of different capacities and sizes.

Table No. 11-a.

Ht. of Water ft. / Cap'cty in Gals.	15					12				
	D	d	L	A_H	A_V	D	d	L	A_H	A_V
100,000	37	10	6·30	·83	·45	40	9	5·64	·68	·38
75,000	32	9	5·55	·80	·33	35·5	8	5·30	·64	·36
50,000	26	8	5·00	·70	·35	29	7	4·6	·58	·31
30,000	20½	7	4·20	·56	·31	22½	7	4·2	·45	·25
10,000	11½	7	3·50	·35	·18	13	6	3·6	·28	·16

Ht. of Water ft. / Cap'cty in Gals.	10					8				
	D	d	L	A_H	A_V	D	d	L	A_H	A_V
100,000	45	8	5·7	·52 ·54	·33	50	7	60	·35	·27
75,000	39	7	4·9	·49	·32 ·32	43½	7	5·2	·35	·27 ·25
50,000	32½	6	4·2	·41	·26	35½	6	3·8	·32	·22 ·23
30,000	25	6	3·9	·38	·21 ·22	28	6	3·5	·28	·19
10,000	15	6	3·3	·27	·14	16	6	3·2	·19	·12

11.2 ILLUSTRATIVE EXAMPLE.

Find the stresses in the walls of a circular tank with 10′ depth of water and of diameter 25 ft.

Assuming the thickness d of walls as 6″

$$H/d=\frac{10}{.5}=20 \quad \text{and} \quad H/D=\frac{10}{25}=.4$$

From charts we have:

(a) position of maximum hoop tension

$L=C_2H=.4\times10=4$ ft. above base.

(b) Maximum hoop tension

$$T=C_1\frac{WH}{2}D$$

$$=.59\times62.5\times10/2\times25=4700 \text{ lbs.}$$

(c) Restraint Moment

$f\,WH^3=0.014\times62.5\times10^3$ ft. lbs.

$=10{,}500$ inch lbs.

Reinforcement:

A_H (for hoop stress) $=\frac{4700}{12000}=.39$ sq. ins. $\frac{1}{2}''\ \phi$ @ 6″ c.c.

A_v (for restraint moment)

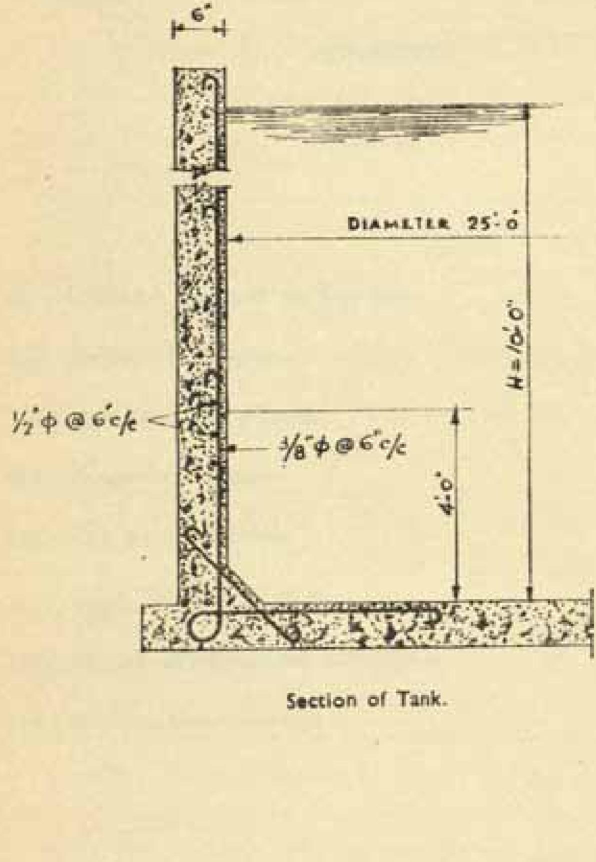
with $\frac{1}{2}''\ \phi$ bars and 1″ cover

effective depth $=6-1.25=4.75''$

Lever arm $=.85\times4.75''$

$$A_v = \frac{10500}{12{,}000 \times .85 \times 4.75} = .22 \text{ sq. ins. approximately}$$

3/8″ ϕ @ **6″** c.c.



Section of Tank.

CHAPTER 12

DIFFERENT KINDS OF CONCRETE

CONTENTS

CHAPTER 12

DIFFERENT KINDS OF CONCRETE

12.1 COLLOIDAL CONCRETE OR COLCRETE.

This is a particular process of making concrete in which stone aggregates which are already laid in position are bound together by cement and sand grout mixed in a special type of mixer. A grout of cement, sand and water mixed in the usual manner is not sufficiently fluid to penetrate between the interstices of the aggregates and produce a dense concrete. Cement particles being very fine are difficult to wet as they cling to each other and are also surrounded by a thin film of air. The surface areas of cement and sand are 80% and 19% respectively of the surface area of all the constituents of concrete. Hence, if these two constituents are efficiently wetted, it is easy to get proper quality of concrete. The special type of machine for mixing the grout is shown below (Fig. 12-1).

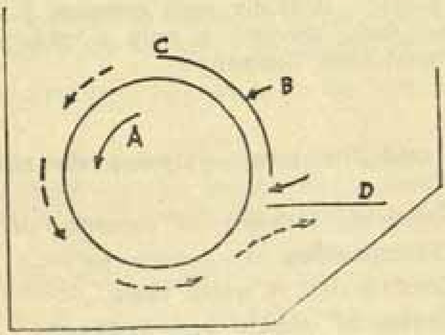


Fig. 12-1.

The roller A about 8″ diameter rotating anticlockwise at 1200 r.p.m. draws in grout through a volute shaped cavity between the drum and the cowl B. The cowl is hinged at C so that the gap at the end of the volute may be adjusted. A knife-edged plate D nearly touches the roller immediately below the back edge of the cowl and cuts off the liquid and directs it to the back of the tank so that complete mixing is secured. After each mixing the grout is tipped into a sump from where it is removed by a pump. In some machines two stage mixing is

done. Cement and water are mixed first and then sand and cement paste subsequently.

Colloidal concrete is very economical as just the required quantity of grout enough to fill in the voids in the coarse aggregate is used. For 1 cubic yard of colloidal concrete only 3 cwts of cement are required as against 5 cwts for usual 1:2:4 mix. Colcrete is very useful in road and runway construction.

12.2 PREPACKED CONCRETE.

The principle of this method of making concrete is the same as above, but instead of using mechanical method of effecting thorough mixture of cement, water and sand, certain chemicals are added to the grout. Cheecol is one such chemical compound.

12.3 SHOT CONCRETE.

12.3.1 DEFINITION.

Cement and sand mortar applied by air pressure is commonly called gunite. Actually such concrete is termed Shotcrete in general and "gunite" is only a trade name for the product of Cement Gun Company.

12.3.2 USES.

Gunite is used for many purposes, the most important being:—

(a) Repairing masonry or concrete structures.

(b) Waterproofing.

(c) Construction of water tanks.

(d) Lining of canals and reservoirs. (Two inches thick gunite is used on brick pitching and three inches of earth slopes.)

(e) Protection of steel from fire, corrosion, etc.

(f) Roof and rib protection in mines.

(g) Walls and roofs etc. of buildings.

12.3.3 PROPERTIES OF GUNITE.

Gunite walls for building are generally 2" thick and are shot on chicken netting stretched against plywood forms. Roofs of buildings are 2 to 3 inches thick. Gunite is used for r.c. domes also.

Strength @ 28 days—6000 lbs./sq. inch average.

Modulus of elasticity—4,670,000 lbs./sq. inch.

W/C ratio required—.25 to .30 (by weight).

Density—⅜" gunite slab could stand 700' head of water
1½ —do— 1600' —do—

12.3.4 NOTES ON SPECIFICATIONS FOR GUNITE WORK.

a. Sand should be of fineness modulus 2.4.

The following grading is recommended:

passing No. 4 sieve	98—100%
8 ,,	70— 95%
16 ,,	60— 85%
30 ,,	45— 65%
50 ,,	15— 35%
100 ,,	0— 5%

Sand should be slightly moist (3 to 8% moisture).

b. Air Pressure: 35 lbs/sq. inch for 100' long hose. Increase 5 lbs for every additional 50 ft.

c. Water Pressure: Should be 15 lbs more than the atmosphere.

d. Material should be shot at right angles to the surface. Loose sand deposits should be removed. A thin edge should be left at each day's work.

e. The following points to be attended to in case of various works:

Steel encasing: fix 2" x 2" mesh wire netting at about ¾" from the surface. Remove paint, rust, etc. and apply gunite 1:3 mix by volume.

Floors: apply 1:3 gunite in one coat upto 3½" thickness. For greater thickness apply in 2 coats the final coat being always more than one inch.

Wall slabs and panels: The thickness to be 1½" upto 4' span and 2" upto 7' span. The steel fabric reinforcement should not be more than 4" mesh and the area should be 3% of wall cross-section in each direction.

Waterproofing of walls: Clean and sand-blast the surface and apply ½" gunite 1:3 mix.

12.3.5 DESIGN DATA FOR GUNITE.

Assumptions: Ultimate compressive stress.

1:3 mix=4100 lbs/sq. inch.
1:2½ mix=4800 —do—

fc	fs	n	j	p	q
1500	20000	.43	.86	.016	276
1800	20000	.47	.84	.021	359
1200	16000	.43	.86	.016	221
1500	16000	.48	.84	.023	305

(Value of modular ratio is 10)

12.4 PRESTRESSED CONCRETE.

12.4.1 PRINCIPLE OF PRESTRESSED CONCRETE.

Principle of prestressed concrete is to introduce internal stresses in the concrete, of nature opposite to those caused by the design load. Hence when the design load operates, the resultant stresses in the concrete are very low.

12.4.2 ADVANTAGES OF PRESTRESSED CONCRETE.

(a) Economy: spans above 100 ft. are not economical in ordinary R.C. work since so much of concrete is wasted in portion below the neutral axis.

(b) It is possible to use high tensile steel reinforcement which cannot be used in ordinary R.C. because of necessity to limit the width of minute cracks in the tensile zone to .02 inches.

(c) The danger of rusting of reinforcement due to atmospheric action in unfavourable areas is entirely eliminated.

12.4.3 METHODS OF PRESTRESSING.

There are two methods:

(a) Prestretched bonded method.
(b) Post-stretched bondless method.

In (a) high tensile steel reinforcement is placed in position and stretched with the help of yokes, hydraulic jacks and abutments. The calculated tension is induced in the wires and concrete is filled into the mould of the prestressed concrete member and allowed to set. When the concrete is sufficiently strong, the tension of the wire is released. The steel while contracting induces compression in the concrete, being bonded to the concrete.

In (b) high tensile steel is placed in the moulds of the prestressed concrete member but is prevented from coming in contact with the concrete being encased in sheaths. The prestressing reinforcement consists of cables made of high tensile steel wires, laid in one or more rings round a core. After the concrete is placed and allowed to attain its normal strength, the high tensile wires are stretched by means of special jacks. The wires are then anchored to the two ends of the beams or structural member by special anchorages. The compression in the concrete is developed through these anchorages instead of through bond between steel and concrete as in method (a).

12.4.4 THEORY.

The prestressing compression being applied eccentrically produces in the section concerned stresses equal to $\frac{F}{A} \pm \frac{Fy^1y}{I}$. These stresses when combined with the tension and compression due to dead and live load bending give the resulting stresses as shown in Fig. 12-2.

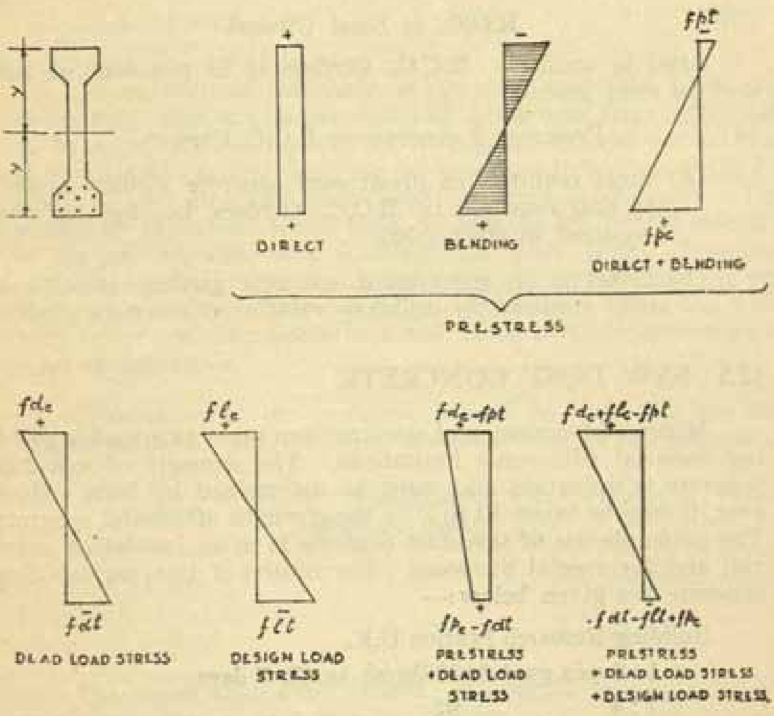


Fig. 12–2

The induced prestressing force is reduced to some extent due to shrinkage of concrete, creep in concrete, plastic flow of steel reinforcement and compression of concrete due to prestressing.

12.4.5 USES OF PRESTRESSED CONCRETE.

Prestressed concrete is being used for various structural items such as bridges, large span roofs, precast roofing joists, railway sleepers, tanks, pressure pipes, etc. etc. The following statements will give some idea about the comparative dimensions and economic possibilities of prestressed concrete.

(1) Prestressed concrete girders *vs* steel joists.

For the same Loading

(a) Prestressed concrete girders are twice the weight of steel joists.

(b) Prestressed concrete girders are one and a half times deeper than steel joists.

(2) R.C.C. *vs* Steel Girders

Steel in ordinary R.C.C. Girders is 10 per cent of that used in steel joists.

(3) Prestressed concrete *vs* R.C.C. Girders

(a) Steel required in prestressed concrete girders is 25% of that required in R.C.C. Girders, i.e., 2½% of that required in steel joists.

(b) Concrete in prestressed concrete girders is 50% of that required in ordinary reinforced concrete girders.

12.5 SAW DUST CONCRETE.

Mixture of cement and saw-dust can serve as a useful building material with some limitations. The strength of saw-dust concrete is uncertain and must be determined by tests. However, it may be taken 10 to 20% the strength of normal concrete. The principle use of saw-dust concrete is as an insulating material and for special purposes. The results of tests on saw-dust concrete are given below:—

Building Research Station U.K.

1 : 2 mix gavè 1190 lbs/sq. in. @ 7 days

1 : 4 „ 92 „

New Zealand: (with Pinus insignus as aggregates)

1 : 2 mix gavè 1190 lbs/sq. in.

1 : 4 „ 725 lbs/sq. in.

The following results are also experimentally found with pine wood saw-dust.

Mix	Comp. strength @ 7 days ultimate.	Density
1 : 2	1100	75
1 : 3	500	49
1 : 4	150	41
1 : 6	110	40
1 : 1½ sand : 1½	1300	100

The extractable materials in saw-dust upset the hardening of cement. This can be prevented by using dust from soft woods or by using 20% of lime or 5% of calcium chloride in the mix. It is advisable to first immerse the saw-dust in boiling water for about 10 minutes and then wash it freely with water. This should be repeated second time, by mixing 2% ferric sulphate in the boiling water and washing the dust again. Saw-dust concrete absorbs water and hence expands and shrinks on getting wet and dry. This can be prevented by coating the units with water resisting substances and using certain percentage of sand as aggregate.

Consistency of the concrete should be such that the mix compacts itself. The following amounts of water are suggested:

Cement	Saw-dust (slightly damp)	Water
94 lbs.	1 cft.	5.5 gallons
	2 cft.	5.9 gallons

The finish should be smooth but even, heavy trowelling should not give cement skin on the top.

12.6 LIGHT WEIGHT CONCRETE.

Is frequently used in making precast blocks, etc., to keep down the weight of the units. Research has shown that it is possible to make concrete of low cement content, with excellent workability, sufficient strength and adequate heat insulation and effect appreciable economy in structural load of a building.

12.6.1 METHODS.

Lightweight concrete is made by

(a) Using light and porous aggregate such as breeze, pumice, etc.

(b) By adding to the cement slurry, containing little or no aggregate, an aerating agent which causes the paste to foam so that the set material contains a certain proportion of air.

12.6.2 LIGHT AGGREGATES.

These are of three types.

(a) Natural: such as pumice, breeze, etc.

(b) By-products: such as Blast-furnace slag, coke, breeze, cinders, saw-dust, etc. etc.

(c) Processed aggregates such as
Exfoliated Vermiculite—a type of mica expanded by heat.

Sintered diatomite—a processed diatomite with soft chalky particles.

Perlite—an expanded perlite composed of frothy particles.

Expanded clay.

Sintered fly ash—a processed material resulting from the combustion of powered fuel in steam power plants.

12.6.3 AERATED CONCRETE.

Hydrogen gas bubbles are generated in a mix containing lime or cement by incorporation of finely divided aluminium or zinc powder about 0.1% of cement. The cellular structure produced in this way is retained after the cement has set and a lightweight product obtained thereby. Sometimes a foaming agent is used, instead of the metal powder, and the mix is whipped up in a special mixer to a fine foam. The weight of aerated cement is 40 to 60 lbs per c.ft.

Properties of Light Weight Concrete

Material	Mix	Wt. Lbs/cft.	Compressive strength lbs./sq. in.	Transverse strength lbs./sq. in.	Shrinkage %	Thermal conductivity.
Pumice Concrete	1 : 6	45—70	200—550	100—150	·04— ·08	1·4 B.th.U
-do-	1 : 10					1·1
Clinker Concrete	1 : 6	50—105	150—450	75—250	·03—0·20	2·8
-do-	1 : 10					2·3
Foamed Slag Concrete	1 : 6	80—95 } 60—95 }	300—500	200—300	0·03—0·05	1·5—2·2
Cellular Concrete	1 : 12	37—60	200—500	100—240	0·05—0·18	1—2
Ballast Concrete	1 : 2 : 4	140—150	3000—5000	300—600	0·03—0·04	7·0

12.7 PRECAST (PREFABRICATED) CONCRETE.

Precast (Prefabricated) Concrete is getting popular day by day.

12.7.1 ADVANTAGES.

(a) Economy in form work.

(b) Possibility of standardization and employment of machinery for manufacture.

(c) Controlled weather conditions.

(d) Use of experienced and skilled workmen.

(e) Temperature effects in the structure are negligible due to many construction joints.

(f) Defective components can be easily rejected.

12.7.2 DISADVANTAGES.

(a) Repeated handling may break the units.

(b) The problem of connecting various units properly is difficult.

12.7.3 REQUIREMENTS.

Precast concrete units must be strong and at the same time light. It is, therefore, necessary to use light-weight concrete in case of non-structural units. Structural units are made either hollow or flanged or are in prestressed concrete so as to cut down the quantity of concrete. It is also necessary to use special methods of consolidation and curing such as vibration, shocks, spinning, steam or electric curing, etc. The concrete also is

very carefully designed and made. Typical sections of structural precast concrete units are shown in Fig. 12-3 (on facing page).

12.7.4 APPLICATIONS.

Precast concrete is used for numerous purposes, the following being only a typical list of most important items:

Floors: Channel beams, hollow beams, T-beams, I-beams, etc.

Foundation:	Sockets for wooden or steel column		
	plates	—do—	
	pedestals	—do—	etc.
	piles	—do—	

Building frames: Portals, gabled frames, etc.

Building units: Hollow and solid blocks, lintels, wall panels (Hollow or solid), window and door sills, cornices, string courses, chimneys, trusses, roofing tiles, etc.

Bridges: Bridge girders, slabs, arch voussoirs.

Miscellaneous: Pipes, transmission line poles, garden furnitures, drains, silos, tanks, railway sleepers, etc.

12.8 AIR-ENTRAINED CONCRETE. (See Para 1.1.2.8)

It is possible to cause in the concrete the inclusion of millions of microscopic bubbles during the process of mixing by using a small amount of certain chemicals either in the mixing water or in the cement. Each bubble of air is encased in a hard glazed shell formed by the surface active force generated by the chemical reaction. Thus the formation of the usual capillary channels by which the water enters the concrete, is prevented and there is no possibility of disintegration of the concrete by freezing and thawing or by leaching. The air bubbles give additional workability permitting smaller w/c ratio and consequently better strength. The segregation of the concrete is prevented due to reduction of w/c ratio and action of the air bubbles. It is also possible to give a better finish to the concrete and improve the surface texture by preventing sand streaking. Vinsol resin is the most common air-entering agent. Several proprietary air-entraining agents are available in the market.

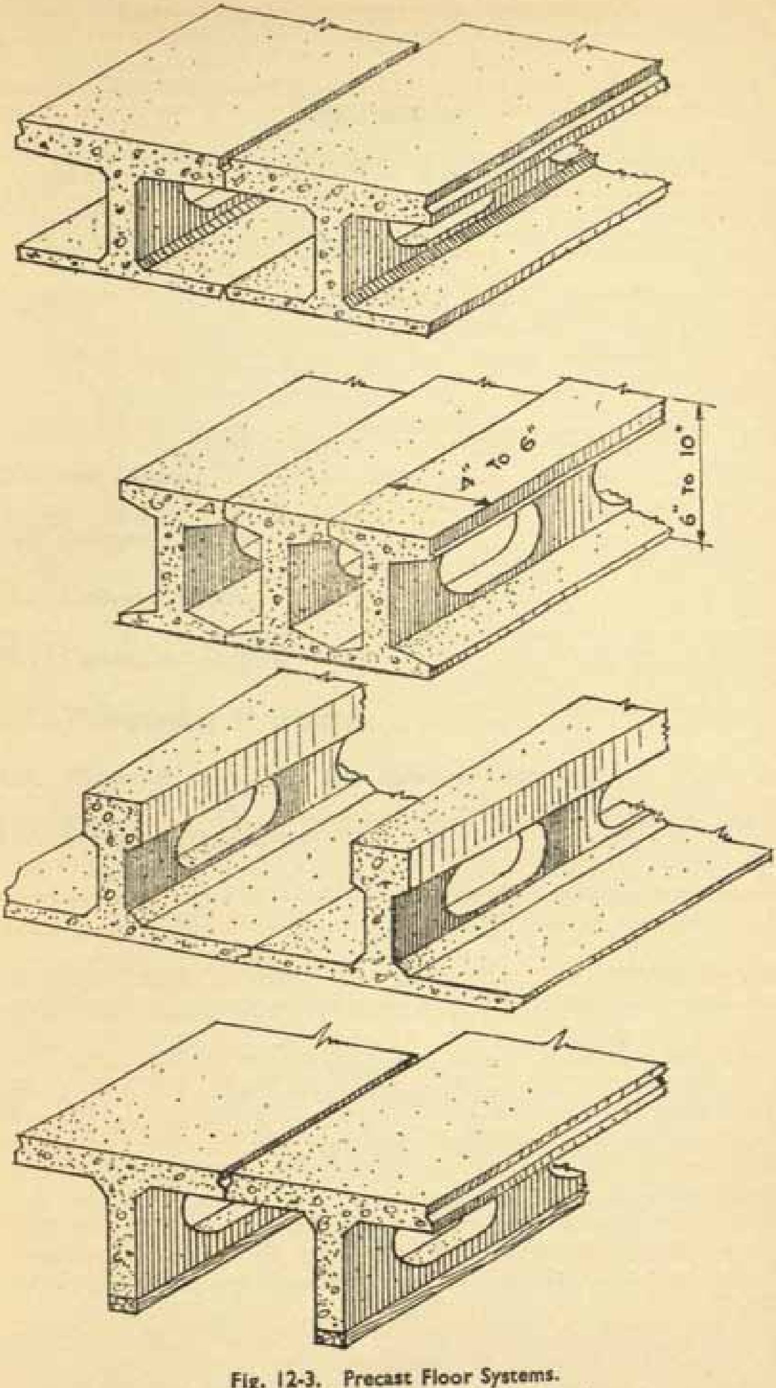


Fig. 12-3. Precast Floor Systems.
I Beam, Rapid Floor Rail System and T Section.

CHAPTER 13

MISCELLANEOUS INFORMATION

CONTENTS

CHAPTER 13

MISCELLANEOUS INFORMATION

13.1 SOIL CEMENT.

Soil cement is a simple intimate mixture of soil with measured amounts of Portland cement and water, compacted to high density. It is mostly used for pavement work.

13.1.1 REQUIREMENTS OF SOIL CEMENT WORK.

(a) Adequate cement content.

(b) Proper moisture content.

(c) Proper density.

The above requirements are determined by tests before starting the work.

(a) Cement content: Cement acts as a binder and by chemical action with water converts the soil cement mixture into a hardened mass.

(b) Water is required to get the necessary workability for the mass to ensure proper compaction and for the hydration of the cement.

13.1.2 TESTS FOR SOIL CEMENT WORK.

Before starting the work it is necessary

(a) to analyse the soil.

(b) to determine how much cement and water should be added to the soil.

(c) to find out the density to which a soil cement mixture should be packed.

(a) Soil is examined for gradation and for any material harmful to cement. The best gradation found by experiment is as follows:—

Sieve designation	% by weight passing square mesh sieve.
No. 3	100
No. 4	55-100
No. 40	15-100
No. 200	0- 50

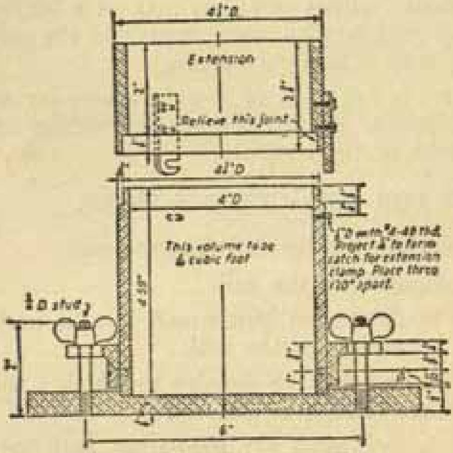
All soil can be broadly divided into three groups.

(1) Sandy and gravelly soils with about 10 to 35% silt and clay combined. These are quite suitable for soil cement work.

(2) Sandy soils deficient in fines like beach sands, wind blown sands, etc. are also suitable but present difficulties in packing and finishing.

(3) Silty and clayey soils also make satisfactory soil cement, but those containing higher clay are difficult to pulverise.

(b) & (c) The approximate minimum moisture content and the approximate minimum volume to which a soil cement mixture should be packed are the optimum moisture and the maximum density. This is determined by means of a special mould and rammer. The soil cement is packed in three layers of equal thickness into a 1/30 c.ft. moisture density mould (also called Procter Mould) with collar attachment.



Cylindrical mould for Moisture-Density Test.

Fig. 13-1.

Each layer is compacted by 25 uniformly spaced vertical blows of a 5½ lb. rammer having a 2" diameter striking face and a free fall of 12". The thickness of the layer is controlled so that the third layer extends over the top of the mould into the collar extension, a distance of about ½ inch. After removing the collar, the soil cement is trimmed to the exact size of the mould

after which the assembly is weighed. The damp weight of the compacted material at different moisture contents is determined in this way, and after determining the moisture content of each test, the dry weights are calculated and then plotted against moisture contents to form a moisture density curve. The optimum moisture content is that at which the greatest dry density is obtained in the test. This density is referred to as the maximum density and is the approximate minimum density to use in soil cement construction. The cement content required to harden the soil will depend upon the nature of the soil and varies from 7 to 16%. It is therefore necessary that the soil on a particular job be tested to determine the safe economical quantity of cement that should be added to it to harden it properly. This is determined by the wetting and drying test. Specimens are alternately subjected to wetting and drying cycles and the loss of material due to two firm strokes of a wire scratch brush is noted.

13.1.3 CONSTRUCTION.

There are two methods followed, viz.:—

(a) mixed in place with heavy duty field cultivators, gang ploughs, rotary speed mixers, etc.

(b) mixed with a travelling type mechanical mixer.

The former is in common use for pavements, etc. and hence described below. The latter is used for cheap type of house construction.

(a) Pavements, roads, etc.

(i) Initial preparation of the site is made and grades, etc. fixed properly.

(ii) Pulverization: A depth of about 5½″ is ripped up by means of pulverizing equipment. Offset disc harrows with 24 to 26 inches discs and rotary speed mixers are then used to break up the soil lumps. During this pulverization a 3 or 4 bottom plough is used to assist in cutting a level subgrade for exposing the edge of the pavement by throwing the material towards the centre, and for bringing up the lumps from the bottom.

(iii) Spreading cement: This is done by hand or by mechanical spreaders upon the area. By accurate calculation the cement bags are spotted properly.

(iv) Dry mixing: When cement spread is completed the mixing of cement and soil is carried out by

means of spring tooth field cultivators, rotary litters, three or four bottom gang ploughs, offset harrows, etc.

(v) Watering: It is often desirable to prewet the soil the day before, if the soil is very dry. For excellent mixing conditions the moisture contents of the said soil should be two or three percentage below the optimum moisture for the soil at the time the cement is spread. Water is added in as large increments as the equipment and the soil will permit. One gallon of water per sq. yd. per application should be sufficient for most soil. After adding 75% of the required water content, samples of the mixed material are examined. Soil cement when at optimum moisture is just moist enough to moisten the hands and it can pack in the hands to form a tight cast.

(vi) Compaction: This is done by sheepsfoot rollers. When the feet of the roller are at 2″ to 3″ from the surface, a motor grader is used for preliminary shaping. Again the sheepsfoot rollers continue packing until about 1″ of loose material remains. At this stage again the motor grader is used to get the final shape. During this interval small quantity of water may be added. The surface compaction planes formed by the last sheepsfoot rolling are removed by a spike tooth harrow.

(vii) Finishing: This is done by means of a pneumatic tyre roller.

(viii) Curing: This is done by moist earth covering or waterproof paper.

13.2 ASBESTOS CEMENT.

Asbestos cement is a combination of asbestos fibres and Portland cement. Asbestos is an infusible, tough and flexible mineral in fibrous form. The fibres are made of extremely minute threads about $\frac{1}{1000}$ m.m. in diameter. Suitable type of asbestos for asbestos cement products is found in Russia, Canada and South Africa. Neat Portland cement is mixed with about 15% of asbestos fibres in such a way that all fibres are thoroughly coated with fine cement. This composition is kept under great hydraulic pressure until it sets. The asbestos fibres act in the same way as steel reinforcement used in R.C.C.

work, but the mixture possesses the great advantage that it is more resilient. It has been proved to possess indefinite durability and great resistance to transverse and tensile stresses. The cement in these products is reinforced in a most effective manner by an intricate network of carefully blended and opened asbestos fibres.

13.3 CEMENT GROUTING.

Grouting is always done under high or low pressure. High pressure grouting is done at pressures above 100 lbs/sq. inch. There are various methods of pressure grouting such as

(a) Fluid or Pump grouting.

(b) Plastic grouting (air pressure grouting).

(a) is the older method of grouting. Mixtures with a consistency of soft fluid mud are used for injection and usually neat Portland cement or very rich cement and sand mixtures are employed. Since the amount of water used is excessive, the grout has got very little cementing value. A reciprocating pump is used for this work.

(b) Cement mortar, or small aggregate concrete with a slump of 6 to 8 inches are injected by pneumatic pressure by means of special machinery which consists of an air compressor and a grouting chamber as shown in Fig. 13-2. By proper manipulation of the various valves and the by-pass pipe it is possible to charge and discharge the grouter and also agitate the grout.

Grouting is used for various purposes, such as—

(a) Soil stabilization.

(b) Solidification of fractured, porous or fissured rock.

(c) Restoration of completed structures by strengthening the foundations.

(d) Sealing of rock strata, gravel or other water-logged ground formations. Preventing contamination of well water from polluted water oozing through porous strata, etc.

(e) Dry pack concrete construction.

(f) Cast in place pile work, etc.

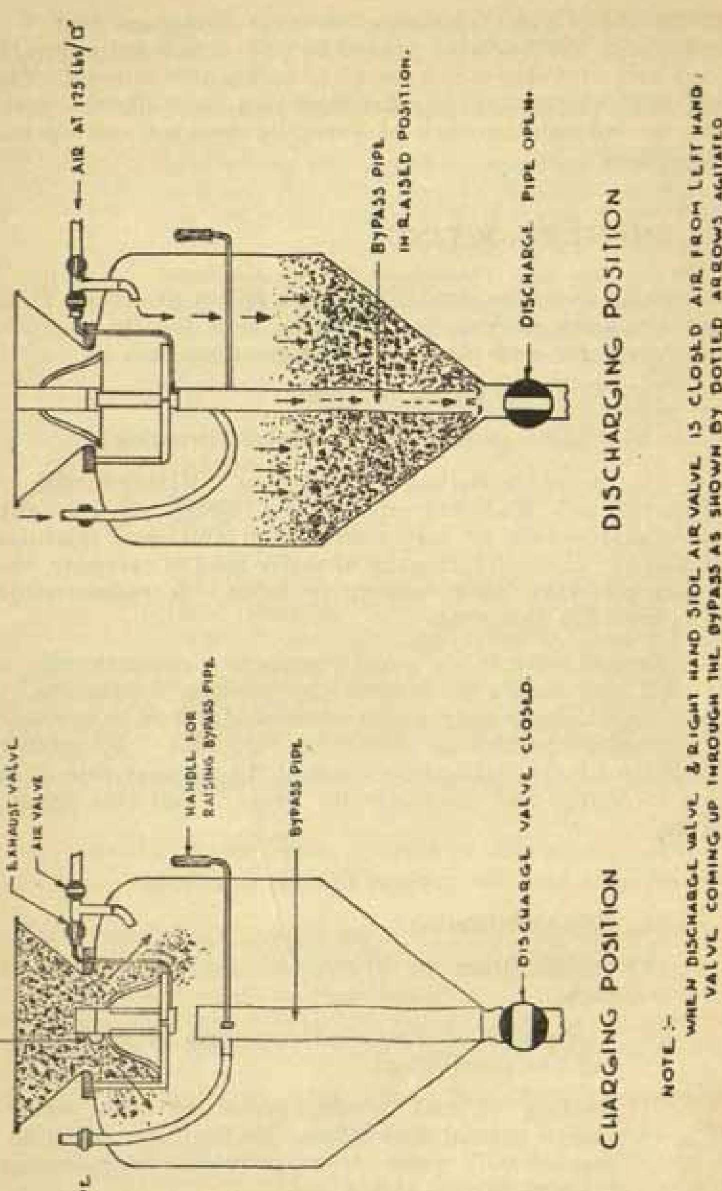


Fig. 13-2. Grouting Machine.

13.4 CEMENT ADMIXTURES.

Admixtures consist of powdered materials to be added to the concrete during its preparation to improve its quality. Most of these are more or less inert and have an indirect effect on the quality of concrete. Admixtures can be classed as of three types, physical, cementacious and pozzolanic.

13.4.1 PHYSICAL ADMIXTURES.

When water is added to the cement, heavier particles of cement settle down and finer particles and water go to the top. The segregation of cement particles is prevented by these admixtures which help in improving the texture of the concrete.

13.4.2 CEMENTACIOUS ADMIXTURES.

These behave more or less like cement and give a richness to the concrete mixture.

13.4.3 POZZOLANIC ADMIXTURES.

Pozzolanic admixtures: These have no cementing value of their own, but they react with the products of hydration of cement to form compounds adding to the strength of the concrete mixture.

Admixtures commonly used are quicklime, slaked lime, diatomeceous earth, bentomite, glue, and salts acting as dispersing agents.

13.5 WATERPROOFING OF CONCRETE.

13.5.1 NECESSITY.

Portland cement concrete has a high resistance to permeation of water when it is gauged with correct quantity of water. In practice, however, we usually add more water to increase the workability and thus increase the voids space in concrete, making it permeable. In order to get water-tight concrete, it is necessary to use clean, well graded, non-porous aggregates with sufficient sand to fill in the void and correct amount of mixing water.

13.5.2 METHODS OF WATERPROOFING.

(a) Use of internal waterproofers.

(b) Surface treatments.

(a) These consist of materials added to cement or concrete. They are available in form of finely ground inert substances such as chalk, diatomaceous earth, silica, dolomitic lime or talc intended to improve the plasticity of the mix and thereby reduce the voids. These are usually employed in conjunction with substances of hydrophobic character e.g. calcium and aluminium soaps. Liquid waterproofers contain substances capable of reacting with a second solution or with cement to form an insoluble product. Examples of this type of solutions are alkali silicates, calcium chloride, zinc sulphate and ordinary soap. Integral waterproofers generally contain calcium chloride soaps, hydrated lime, etc.

(b) These are: Asphalt emulsions, iron salammoniac compounds, cement washes, silicate of soda, boiled linseed oil, gelatinous pastes, etc.

13.5.3 A FEW WATERPROOFING COMPOUNDS LIKELY TO BE AVAILABLE IN BOMBAY.

Name of Product	Sole Agents in India
Sealocrete	McKenzies Ltd., Sewri, Bombay.
Ironite	Heatley & Gresham Ltd., 9, Forbes Street, Fort, Bombay.
Tretol	J. C. Gammon Ltd., Hamilton House, Ballard Estate, Bombay.
Impermo (A.P.C.M.)	The Anglo-Thai Corporation Ltd., Ewart House, Bruce Street, Bombay.
Compo-Seal	Robert Ingham Clark & Co., Lakshmi Building, Sir P.M. Road, Bombay.
Aquella	Turner Hoare & Co. Ltd., Gateway Building, Apollo Bunder, Bombay.
Pudlo	Richardson & Cruddas, Byculla Ironworks, Parel Road, Byculla, Bombay.
Sika	William Jacks & Co., Hamilton House, Ballard Estat., Bombay.

Name of Product	Sole Agents in India
Metarock	Gannon Dunkerley & Co. Ltd., Chartered Bank Building, Fort, Bombay.
Cico (Che-Ko)	Structural Waterproofing Co., 21-1, Davar Road, Ballygunge, Calcutta.
Cemexo	The Unique Waterproofing Co., 28/A Debendra, Calcutta.
Hydrol	H. S. Cox & Co. Ltd., 24 Rampart Row, Bombay 1.
C.C. Case Hardening	—do— —do—
Sodium Silicate	Imperial Chemical Industries, Imperial Chemical House, Dougall Road, Ballard Estate, Bombay.
Visek	Marshall & Sons Ltd., Marshall's Building, Ballard Estate, Bombay.

13.6 EFFECTS OF ACIDS, OILS AND SALTS ON CONCRETE.

Protective Treatments Recommended, Where Required—Directions for their application.

13.6.1 GENERAL CONSIDERATIONS.

The industrial application of this problem is of great importance in numerous cases where chemicals, oils, and various other industrial liquids are kept in storage in reinforced concrete tanks.

The protective treatments recommended are based, as they must be, on the assumption that the concrete is of a suitable quality, which means a well cured, dense, water-tight concrete. This requires:

(a) Low water-cement ratio, not to exceed 6 gal. of mixing water per sack of cement.

(b) Suitable workability, to avoid mixes so harsh and stiff that honeycomb occurs, and those so fluid that water rises to the surface.

(c) Thorough mixing, at least one minute after all materials are in the mixer, or until the mix is uniform.

(d) Proper placing, spacing or vibration to fill all corners and angles of forms without segregation of materials —avoid construction joints.

(e) Adequate curing, protection by leaving forms in place, covering with wet sand or burlap and sprinkling. Concrete to be kept wet and above 50°F. for at least the first week. Not to be subject to hydrostatic pressure during this period.

Many solutions such as brines and salts, which have no chemical effect on concrete, may crystallize upon loss of water. It is especially important that concrete subject to alternate wetting and drying of such solutions be very dense and non-absorbent. If the concrete is porous it will absorb the solution. Since the crystals require more space than the liquid, they exert considerable pressure which may be sufficient to break down the concrete. Salt solutions corrode steel more rapidly than plain water. In structures which are to be subject to frequent wetting and drying by these solutions it may be advisable to provide some surface coating such as sodium silicate, linseed oil or one of the varnishes as an added precaution.

13.6.1 SURFACE TREATMENTS.

Materials are available for almost any degree of protection required on concrete. The more common methods of treatment are indicated in the table, the numbers in the table corresponding to the following numbered paragraphs in which the necessary instructions are given:

(1) Magnesium Fluosilicate or Zinc Fluosilicate.

The treatment consists of two or more applications. First, a solution of about 1 lb. of the fluosilicate crystals per gallon of water is used. For subsequent applications about 2 lb. of crystals per gallon of water is used. Large brushes are convenient for applying on vertical surfaces, and mops on horizontal areas. Each application should be allowed to dry; after the last has dried, the surface should be brushed and washed with water to remove crystals which have formed. The treatment densifies and hardens the surface by chemical action. Fluosilicates are available through dealers in chemicals.

(2) Sodium Silicate (commonly called water glass).

This is quite viscous and must be diluted with water to obtain penetration, the amount of dilution depending on the quality of the silicate and the density of the concrete. Silicate of about 42.5 deg. Baume gravity diluted in proportions of 1 gal. with 4 gal. of water makes a good solution. It may be applied in two or three or more coats, allowing each coat to dry thoroughly. On horizontal surfaces it may be poured on and then spread evenly with brooms or brushes. Scrubbing each coat with water after it has hardened provides a better condition for application of succeeding coats. For tanks and similar structures progressively stronger solutions are often used for the succeeding coats.

(3) Linseed Oil.

Only boiled linseed oil should be used. Applied hot, it gives better penetration. Two or three coats may be applied, allowing each to dry thoroughly before the next application. The concrete should be well cured and seasoned before the first application. Linseed oil is sometimes applied after the magnesium fluosilicate treatment, providing a good coating over a hardened surface.

(4) Cumar.

Cumar is a synthetic resin soluble in xylol and similar hydrocarbon solvents. A solution consisting of about 6 lb. of Cumar per gallon of xylol with ½ pint boiled linseed oil makes a good coating. Two or more coats should be applied. Concrete should be fairly dry. The cumar should be powdered to aid dissolving. It is available in grades from dark brown to colourless.

(5) Varnishes.

Any varnish can be applied to dry concrete. High grade varnishes of the spar, china-wood oil, or bakelite types give good protection against many substances. Good varnishes may contain natural or synthetic resins. Two or more coats should be applied.

(6) Bituminous or Coal Tar Paints, Tar and Pitches.

These are usually applied in two coats, a thin priming coat to insure bond and a thicker finish coat. Concrete must be dry and dust-free. Finish coat must be carefully applied to insure continuity and avoid pin holes. Surface should be touched up where necessary.

(6) Bituminous Enamels.

This is suitable protection against relatively strong acids. It does not resist abrasion at high temperatures. Two materials are used, a priming solution and the enamel proper. The priming solution is of thin brushing consistency and should be applied to dry, dust-free concrete, touching up any uncoated spots before applying the enamel. When primer has dried to a slightly tacky state, it is ready for the enamel. The enamel usually consists of a bitumen with a finely powdered siliceous mineral filler. The filler increases the resistance to flowing and sagging at elevated temperatures, and to abrasion. The enamel should be melted and carefully heated until it is fluid enough to brush. The temperature should not exceed 375°F. When fluid it should be mopped on quickly, as it sets and hardens rapidly.

Bituminous paints and enamels are made by a number of companies.

(8) Bituminous Mastic.

This is used chiefly for floors on account of the thickness of the layer which must be applied, but some mastics can be troweled on vertical surfaces. Some mastics are applied cold. Others must be heated until fluid. The cold mastic consists of two compositions—the priming solution and the body coat or mastic. The primer is brushed on dry, dust-free concrete. When it has dried to a tacky state, a thin layer—about 1/32″ of the mastic is troweled on. When this has dried, successive 1/32″ coats of the mastic are applied, until the required thickness has been built up. The mastic is similar to the primer but is ground with sufficient asbestos and finely powdered siliceous material fillers to make a very thick, pasty fibrous mass.

The hot mastics are somewhat similar to the mixtures used in sheet asphalt pavements, but contain more asphaltic binder so that when heated to fluid condition, they can be poured and troweled into place. They are satisfactory only when applied in layers of 1 in. or more in thickness. When ready to lay, the mixture usually consists of about 15 per cent asphaltic binder, 20 per cent finely powdered siliceous mineral filler, and the remainder is sand graded up to ¼ in. maximum size.

Masties are made by a large number of manufacturers.

(9) Vitrified Brick or Tile.

These are special burnt clay products which are not attacked by acids or alkalies. They must, of course, be laid in

mortar which is also resistant against the substance to which they are to be exposed. A bed of the mortar is usually placed between the brick or tile and concrete. Some of the acid-proof cements are melted and poured in the joints. Many manufacturers make acid-proof brick and cement.

(10) Glass.

May be cemented to the concrete.

(11) Lead.

May be cemented to the concrete with an asphaltic paint.

(12) Rubber.

One of the largest rubber companies in U.S.A. contracts to treat tanks and other structures with their "Acid-Seal". The material is not for sale to other contractors.

13.7 EFFECT OF ACIDS, OILS AND OTHER PRODUCTS, ON UNPROTECTED CONCRETE, WITH PROTECTIVE TREATMENTS, WHERE REQUIRED.

ACIDS.

Material	Effect on Concrete	Surface treatment
Acetic	Disintegrates slowly	5, 6, 7
Acid waters	Natural acid waters may erode surface mortar, but usually action then stops	1, 2, 3, 4, 5, 6, 7
Carbolic	Disintegrates slowly	1, 2, 3, 5
Carbonic	Disintegrates slowly	2, 3, 4, 5, 6, 7
Humic	Depends on humus material but may cause slow disintegration	1, 2, 3, 4, 5, 6, 7
Hydrochloric	Disintegrates	8, 9, 10, 11, 12
Hydrofluoric	Disintegrates	8, 9, 11, 12
Lactic	Disintegrates slowly	1, 2, 3, 4, 5, 6, 7
Muriatic	Disintegrates	8, 9, 10, 11, 12
Nitric	Disintegrates	8, 9, 10, 11, 12
Oxalic	None	None
Phosphoric	Attacks surface slowly	1, 2, 3, 4, 5, 6, 7
Sulphuric	Disintegrates	8, 9, 10, 11, 12
Sulphurous	Disintegrates	8, 9, 10, 11, 12
Tannic	Disintegrates slowly	1, 2, 3, 4, 5, 6, 7

SALTS AND ALKALIES

Material	Effect on Concrete	Surface treatment
Carbonates of Ammonia, Potassium, Sodium	Weak solutions and dry salts will not affect concrete. Strong solutions may cause slow disintegration and concrete should be treated	1, 3, 4, 5, 6, 7
Chlorides of Calcium, Potassium, Sodium	None unless concrete is alternately wet and dry with the solution, when it is advisable to treat with.	1, 3, 4, 5, 6, 7
Chlorides of Ammonia, Copper, Iron, Magnesium, Mercury, Zinc	Disintegrates slowly	1, 3, 4, 5, 6, 7

Material	Effect on Concrete	Surface treatment
Fluorides	None except ammonium fluoride	3, 4, 5, 6, 7
Hydroxides of Ammonia, Potassium, Sodium	Disintegrates	1, 3, 4, 5, 6, 7
Nitrates of		
Ammonia	Disintegrates	8, 9, 10, 11, 12
Calcium	None	None
Potassium	Disintegrates slowly	1, 3, 4, 5, 6, 7
Sodium	Disintegrates slowly	1, 3, 4, 5, 6, 7
Potassium Permanganate	None	None
Silicates	None	None
Sulphates of Ammonia	Disintegrates	8, 9, 10, 11, 12
Aluminum, Calcium, Cobalt, Copper, Iron, Manganese, Nickel, Potassium, Sodium, Zinc	Disintegrates	1, 3, 4, 5, 6, 7

PETROLEUM OILS

Material	Effect on Concrete	Surface treatment
*Heavy oils below 30° Baume	None	None
*Light oils above 30° Baume	None—Some loss from penetration	1, 2, 3, 5.
Benzine Gasoline Kerosene Naphtha	None—Considerable loss from penetration	1, 2, 3, 5.

*Many lubricating and other oils contain some vegetable oils. Concrete exposed to such oils should be protected as for vegetable oils:

Material	Effect on Concrete	Surface treatment
Coal	Great majority of structures show no deterioration. Exceptional cases have been coal high in pyrites (sulphide of iron) and moisture showing some action but the rate is greatly retarded by deposit of an insoluble film. Action may be stopped by surface treatments	1, 2, 3, 4, 5, 6, 7
Corn syrup	Disintegrates slowly	1, 2, 3, 4, 5, 6, 7
Electrolyte	Depends on liquid. For lead and zinc refining use.	7, 8, 9, 10 12
Formalin	Aqueous solution of formaldehyde disintegrates concrete.	9, 10, 11, 12
Fruit juices	Most fruit juices have little if any effect as tartaric acid and citric acid do not appreciably affect concrete. Floors under raisin seeding machines have shown some effect, probably due to poor concrete.	1, 2
Glucose	Disintegrates slowly	1, 2, 3, 4, 5, 6, 7
Glycerine	None	None
Honey	None	None
Lye	Same as sodium hydroixde	1, 2, 3, 4, 5, 6, 7

Material	Effect on Concrete	Surface treatment
Milk	Sweet milk should have no effect but if allowed to sour the lactic acid will attack.	1, 2, 3, 4, 5, 6, 7
Molasses	Does not affect dense, thoroughly cured concrete. Dark, partly refined molasses may attack concrete that is not thoroughly cured. Such concrete may be protected with	2, 5
Nitre	Same as nitrate of potassium	1, 3, 4, 5, 6, 7
Sal ammoniac	Same as ammonium chloride—causes slow disintegration	1, 3, 4, 5, 6, 7
Sal soda	Same as sodium carbonate	1, 3, 4, 5, 6, 7
Salt petre	Same as nitrate of potassium	1, 3, 4, 5, 6, 7
Sauserkraut	Little, if any, effect. Protect taste with.	1, 2
Silage	Attacks concrete slowly	3, 4, 5, 6, 7
Sugar (cane or beet)	No effect on concrete that is thoroughly cured.	None.
Sulphite liquor	Attacks concrete slowly	1, 2, 3, 4, 5, 6, 7
Tanning liquor	Depends on liquid. Most of them have no effect. Tanneries using chromium report no effects. If liquor is acid, protect with	1, 2, 3, 4, 5, 6, 7
Vinegar	Disintegrates (See acetic acid)	1, 2, 3, 4, 5, 6, 7
Washing soda	Same as sodium carbonate	1, 3, 4, 5, 6, 7
Whey	The lactic acid will attack concrete	1, 2, 3, 4, 5, 6, 7
Wine	Many wine tanks with no surface coating have given good results but taste of first batch may be affected unless concrete has been given tartaric acid treatment	For fine wines the concrete has been treated with 2 or 3 applications,* (1 lb. tartaric acid in 3 pints water.) Sodium silicate is also effective. In a few cases tanks are lined with glass-tile.
Wood pulp	None	None.

* of tartaric acid solution.

Material	Effect on Concrete	Surface treatment
Alizarin Anthracene Benzol Carbozol Cumol Paraffin Pitch Toluol Xylol	None	None
Carbolineum Creosote Cresol Lysol Phenol	Disintegrates slowly	1, 2, 3, 5

VEGETABLE OILS

Material	Effect on Concrete	Surface treatment
Cotton seed	No action if air is excluded. Slight disintegration if exposed to air.	None 1, 2
Rosin	None	None
Almond Castor *China-wood Cocoanut *Linseed Olive Peanut Poppy seed Rope seed Soy-bean Tung Walnut	Disintegrates surface slowly	1, 2
Turpentine	None—Considerable penetration	1, 2

* Applied in thin coats the material quickly oxidizes and has no effect. Results indicated above are for constant exposure to the material in liquid form.

FATS AND FATTY ACIDS (Animal)

Material	Effect on Concrete	Surface treatment
Fish oil	Most fish oils attack concrete slightly. Menhaden oil does not.	1, 2
Folio to Lard and lard oil Tallow and tallow oil	Disintegrates surface slowly	1, 2

MISCELLANEOUS

Material	Effect on Concrete	Surface treatment
Alcohol	None	None
Ammonia water (Am. Hydrozide)	Disintegrates slowly	1, 3, 4, 5, 6, 7
Baking soda	Same as sodium bicarbonate—no effect in weak solutions and dry salts. For strong solutions treat concrete.	1, 2, 3, 4, 5, 6, 7
Beer	Beer will cause no progressive disintegration of concrete, but in beer storage and fermenting tanks a special coating is used to guard against contamination of beer	Coating made and applied by a New York Company.
Bleaching powder	Mixtures of calcium chloride and calcium hypochloride do not affect dense concrete.	None
Borax, boracic acid, boric acid	No effect	None
Brine (salt)	No effect on dense concrete. Where subject to frequent wetting and drying of brine provide	1, 2, 3, 4, 5, 6, 7
Buttermilk	Same as milk	1, 2, 3, 4, 5, 6, 7
Charged water	Same as carbonic acid—slow attack	1, 2, 3, 4, 5, 6, 7
Caustic soda	(Sodium hydroxide) Disintegrates	1, 2, 3, 4, 5, 6, 7
Cider	Disintegrates (See acetic acid)	1, 2, 3, 4, 5, 6, 7
Cinders	May cause some disintegration	1, 2, 3, 4, 5, 6, 7

CHAPTER 14

GENERAL DATA, TABLES, ETC.

CONTENTS

CHAPTER 14

GENERAL DATA, TABLES, ETC.

Crushing Strength of Stones

	Tons/s.ft.
Granite	1000 to 700
Trap	400
Basalt	1000
Sandstone (Hard)	600
" (Medium)	400
Limestone (Hard)	400
" (Soft)	100
Brick (1st Class)	100
Cement concrete 1 : 2 : 4	180

Strength of Lime Mortars

		3 months Tons/sq.ft.	27 months Tons/sq.ft.
Hydraulic Kankar Lime	1:1	71	107
	1:1½	66	104
	1:2	64	118
	1:2½	52	104
	1:3	46	85
Fat lime	1:2	48	—
—do— Surkhi	2:1:6	59	—
—do— Blacksoil Surkhi	2:1:6	49	—

Safe Permissible Loads on Masonry.

		Tons/s.ft
1.	Brick in mud	1¼
2.	Brickbat concrete in lime	2
3.	Stone metal concrete in lime	3 to 3½
4.	Laterite masonry in lime	2
5.	—do— (good quality stone)	3

		Tons/s.ft.
6.	Country brickwork in lime	2 to $3\frac{1}{2}$
7.	1st Class " "	4 to 5
8.	C. R. Masonry in lime	3.5 to 7
9.	—do— (granite)	5
10.	Country bricks in cement	4 to 6
11.	1st Class bricks —do—	8
12.	Granite ashlar	15
13.	Trap —do—	20
14.	Cement Concrete	
	1 : 2 : 4	32
	1 : 3 : 6	25
	1 : 4 : 8	19

Wind Pressures in India & Pakistan.

40 LBs/sq. ft.
Karachi Dist., Cutch and Saurashtra.

20 LBs./sq. ft.
Madras, Vellore, Nellore & Masulipatam Districts.

15 LBs/sq. ft.
Makran, Hyderabad (Sind), Deesa, Ahmedabad, Surat, Bombay, Poona, Ratnagiri, Goa, Belgaum, Karwar, Mangalore, Mercara, Coconada, Vizagapatam, etc.

10 LBs/sq. ft.
For the rest of India and Pakistan.
The above allowance is on safe side.

Wind velocity and pressure.

	Nature of wind.	Equivalent velocity miles 1 hour.	Mean wind pressure lbs. per sq. foot.
1.	Moderate breeze	15	0.67
2.	Fresh breeze	21	1.31
3.	Strong breeze	27	2.30
4.	Strong gale	50	7.70
5.	Whole gale	59	10.50
6.	Storm	68	14.00

Water velocity and pressure.

$P = 1.8V^2$ for fresh water.

$= 1.85V^2$ for salt water.

V = velocity of current in feet/sec.

P = pressure on a plane normal to the current in lbs. per sq. foot.

WORKING STRESSES FOR TIMBER

(lbs. per sq. inch.)

No. 1 Quality.

Name	Youngs Modulus.	Bending			Sheer	Compression Parallel to grain			Compression Perpendicular to grain		
		A	B	C		A	B	C	A	B	C
Burma Teak	1600	2200	2000	1570	125	1700	1580	1230	700	520	420
C. P. „	1200	1820	1650	1300	120	1380	1280	1000	670	500	400
Yellow Pine	1630	1740	1580	1240	120	1350	1250	980	400	300	240
Kail	986	950	860	680	110	970	900	700	170	125	100
Deodara	1348	1740	1580	1240	100	1370	1270	990	440	330	260
Sal	1920	2120	1930	1510	175	1510	1400	1090			
Jarrah	1500	2300	2000	1640	—	870	810	630			
No. 2 Quality.											
Burmah Teak	1400	1830	1600	1300	115	1380	1230	1000	600	470	380
C. P. „	1050	1510	1300	1070	110	1120	1000	810	570	450	360
Yellow Pine	1420	1450	1240	1020	105	1100	980	800	340	270	220
Kail	858	790	680	560	95	790	700	570	140	110	90
Deodara	1170	1440	1235	1020	90	1110	990	810	380	295	240
Sal	1670	1770	1510	1250	160	1230	1090	890			
Jarrah	1300	1910	1640	1350	..	710	630	510			

Note: A Inside location.
B Outside location.
C Wet location.

DAILY TASK WORK FOR ARTISANS & LABOURERS.

(Working day 8½ hours)

(1) Excavation: (5′ lift & 100′ lead)

a	earth	75 cft. per man
b	soft murum	50 ,, ,,
c	average murum	35 ,, ,,
d	hard murum	25 ,, ,,
e	soft rock	16 ,, ,,
f	hard rock	8 ,, ,,

(2) Breaking metal

trap stone 1½″ size		10 cft. per man
quartz	-do-	13 ,, ,,
laterite	-do-	20 ,, ,,
brick	-do-	50 ,, ,,

(3) Conveying metal on head

lead 100 ft.	85 cft. per man
200 ,,	65 ,, ,,
300 ,,	50 ,, ,,
600 ,,	35 ,, ,,

(4) Masonry

a	ashlar stone		2 cft. one mason & 1 man
b	coarsed rubble	1st class	9 ,, ,, ,,
	-do-	2nd ,,	12½ ,, ,, ,,
	-do-	3rd ,,	20 ,, ,, ,,
c	brick	1st class	17 ,, ,, ,,
	,,	2nd ,,	25 ,, ,, ,,

(5) Plastering

¾″ thick cement	33 s.ft. one mason & 1 man
rough cast	90 ,, ,, ,,
pointing	60 ,, ,, ,,

(6) Flooring

	Flagstone (lâdi)	30 to 40 sq. ft.
	Dressed trap stone	5 ,,
	Cement concrete	30 ,,

(7) Carpenter

a	Panelled doors $4' \times 7'$	10 days per piece
b	Plain planked	4 ,,
c	Glazed windows	6 ,,
d	Venetianed windows	14 ,,
e	Teakwood work (framing)	2 cft.
f	-do- (joinery)	1 ,,
g	Woodwork in Mangalore tiled roof	100 sft.
h	-do- in G.C.I. roof	33 ,,

(8) Precast concrete works
(in steel moulds)

a	Pipes 6" diameter	12 nos.
b	Roofing tiles	90 ,,
c	Hollow blocks (in hand machine)	100 ,, (1 mason & 2 coolies)
d	Paving flags	30 ,,

(9) Cutting and bending reinforcement

$\frac{1}{4}'' \phi$ to $\frac{3}{8}'' \phi$	2 cwts.
$\frac{1}{2}'' \phi$	$2\frac{1}{2}$,,
$\frac{5}{8}'' \phi$ to $2'' \phi$	4 ,,

(10) Erecting formwork — 20 s.ft.

(11) Finishing

a	Whitewashing 3 coats	400 s.ft.
b	Distempering	200 ,,
c	Cement washing 2 coats	400 ,,

Mensuration

Circumference of circle	Dia × 3.1416
Side of an equal square	Dia × .8862
Side of an inscribed square	Dia × .7071
Area of a circle	$\text{Dia}^2 \times .7854$
Area of a sector	length of arc × $\frac{1}{2}$ radius
Ellipse	.7854 × long axis × short axis
Parabola	Base × height × $\frac{2}{3}$
Parallelogram	Height × base
Trapezium	Sum of parellal sides × H/2

Volume or surfaces.

Lateral surface of a sphere		$4 \pi r^3$
,, ,,	cylinder	$2 \pi rh$
,, ,,	cone	$\pi r\, h^2 + r^2$
Contents of a sphere		$\frac{4 \pi r^3}{3}$
do	cone	$\pi r\, h^2 + r^2$
do	cylinder	$2 \pi rh$
do	pyramid	area of base × perpendicular height ÷ 3

PROPERTIES OF THE CIRCLE

Chord of angle A $= \dfrac{c}{r}$

Versed sine of angle $\frac{1}{2}$A $= \dfrac{h}{r}$

$$= 1 - \text{Cos}\ \frac{A}{2}$$

Area of circle $= \pi r^2 = .7854d^2$

Circumference of circle $= 2\pi r$

$\pi = 3.141593 \qquad \pi^2 = 9.869604$

Arc length abc = rA (A in radians)

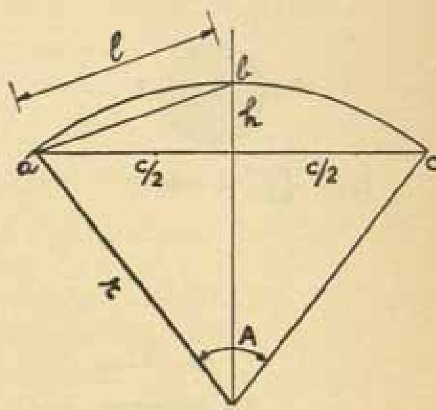
one radian = 57.296°

$$l = \sqrt{h^2 + c^2/_4}$$

$$c = 2\sqrt{2rh - h^2}$$

$$r = \frac{4h^2 + c^2}{8h}$$

$$h = r - \sqrt{r^2 - c^2/_4}$$



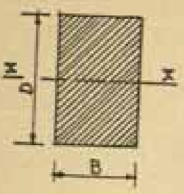
I about a diameter $= \dfrac{\pi d^2}{64} = .0491d^2$

Side of a square having periphery equal to circumference of circle $\dfrac{r\pi}{2}$

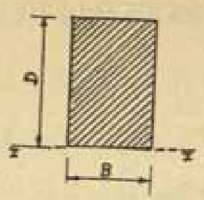
Diameter of a circle circumscribed about a square = side of square × 1.41421.

AREAS OF SMALL CIRCLES ADVANCING BY 32nds OF AN INCH

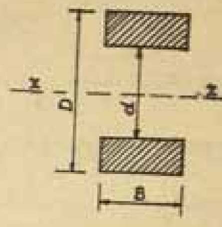
Diameter in inches	Area sq. inches	Diameter in inches	Area sq. inches	Diameter in inches	Area sq. inches	Diameter in inches	Area sq. inches
1/32	·0008	9/32	·0621	3 7/12	·2217	25/32	·4794
1/16	·0031	5/16	·0767	3/16	·2485	13/16	·5185
3/12	·0069	11/32	·0928	19/32	·2769	27/32	·5591
1/8	·0123	3/8	·1104	5/8	·3068	7/8	·6013
5/32	·0192	13/32	·1296	21/32	·3382	29/32	·6450
3/16	·0276	7/16	·1503	11/16	·3712	15/16	·6903
7/32	·0376	15/32	·1726	23/32	·4057	31/32	·7371
1/4	·0491	1/2	·1963	3/4	·4418	1	·7854



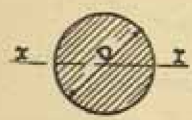
$$I_{xx} = \frac{BD^3}{12}$$



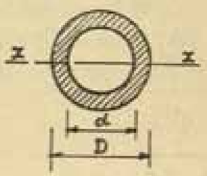
$$I_{xx} = \frac{BD^3}{3}$$



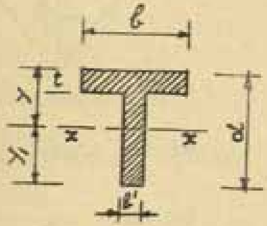
$$I_{xx} = \frac{B(D^3 - d^3)}{12}$$



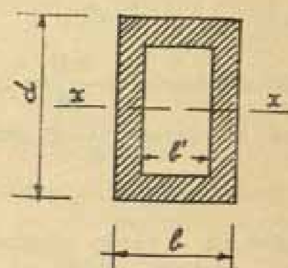
$$I_{xx} = \frac{\pi D^4}{64} = \cdot 0491\ D.$$



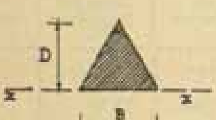
$$I_{xx} = \frac{\pi (D^4 - d^4)}{64} = \cdot 0491 (D^4 - d^4)$$



$$I_{xx} = \frac{b' y_1^3 + b y^3 - (b - b')(y - t)^3}{3}$$

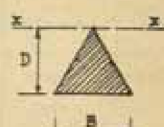


$$I_{xx} = \frac{bd^3 - b_1 d^3}{12}$$



$$I_{xx} = \frac{BD^3}{12}$$

$$I_{xx} = \frac{BD^3}{36}$$



$$I_{xx} = \frac{BD^3}{4}$$

Moments of Inertia of Sections.

Weights & Measures.

8 Ruttees	=	1 masha	=	3/175 dr.	Avois
12 mashas	=	1 Tola	=	12/175	,,
5 Tolas	=	1 chattak	=	$2\,^2/_{35}$ ozs.	,,
16 chattaks	=	1 seer	=	$2\,^2/_{35}$ lbs.	,,
40 seers	=	1 maund	=	$82\,^2/_{27}$ lbs.	
4 chattaks	=	20 Tolas	=	$2\,^2/_{35}$ lbs.	
4 Paus	=	1 seer			
5 seers	=	1 Pansari			

---

16 Drams	=	1 ounce
16 ounces	=	1 pound
14 pounds	=	1 stone
28 pounds	=	1 quarter
112 pounds	=	1 hundredweight (cwt.)
20 cwts.	=	1 Ton.

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4 inches	=	1 hand
9 inches	=	1 span
12 inches	=	1 foot
3 feet	=	1 yard
5 feet	=	1 pace
6 feet	=	1 fathom
5½ yards	=	1 rod pole
4 poles	=	1 chain
10 chains	=	1 furlong
8 furlongs	=	1 mile (one nautical mile=6080 ft.
3 miles	=	1 league 1 Knot = 1 nautical mile/hour.)

---

144 square inches	=	1 square foot
9 square feet	=	1 square yard
30¼ square yards	=	1 square perch
40 perches	=	1 rood
4 roods	=	1 acre
640 acres	=	1 square mile
an acre	=	4840 sq. yds.

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cubic foot	=	1728 cubic inches
cubic yard	=	27 cubic feet
stack of wood	=	108 cubic feet.

Metric Measures.

(1) Length:

Millimeter (m.m.)			=	.039370 inches	
Centimeter	=	10^1 m.m.	=	.393704	,,
Decimeter	=	10^2 m.ms	=	3.937043	,,
Meter	=	10^3 m.ms	=	39.370428	,,
Decimeter	=	10^4 m.ms	=	393.70428	,,
				=	32.80869 ft.
Hectometer	=	10^5 m.ms	=	=	328.0869 ft.
Kilometer	=	10^6 m.ms	=	=	3280.869 ft.

(2) Area

Square millimeter ($m.m^2$)			=	.001550 sq. inches.
Sq. Centimeter	=	10^2 sq. m.ms	=	.1550 sq. inches
Sq. Decimeter	=	10^4 sq. m.ms	=	15.5003 sq. inches
Sq. Meter	=	10^6 sq. m.ms	=	1550.03 sq. inches
			=	10.764 s.ft.
Sq. Kilometer	=	10^{12} sq. m.ms	=	10764101 s.ft. or
	=	10^6 sq. meters.		247.11 acres.

(3) Capacity.

Millilitre	=	.0610254 Cubic inches.		
Centilitre	=	10 Mililitres	=	.610254 Cubic in.
Litre	=	10^3 mililitres	=	61.0254 Cubic in.
Kilolitre	=	35.3156 Cubic ft.		

(4) Weight.

Milligramme $= \frac{1}{10}$ Centigramme $= \frac{1}{10^3}$ gramme = .015432 grains.

Gramme	=		=	0.03527 oz.
Kilogramme	=	10^3 grammes	=	2.2046 lbs.
Tonne	=	1000 Kilogrammes	=	.9843 Tons.

(5) Volume.

1 Cubic Centimeter (c.c.)	=	.06103 Cubic inches.		
1 Cubic Meter	=	1,000,000 c.cs	=	35.3156 Cubic ft.
			=	1.31 Cubic yds.

Conversion factors.

Multiply by	To convert	To	
7000	Pounds (avoir)	Grains (troy)	.000143
28.35	Ounces (avoir)	Grammes	.0352
.065	Grains	-do-	15.38
50.8	Cwts.	Kilogrammes	.01968
1016.0	Tons	-do-	.000984
4.546	Gallons	Litres	.22
10	Gallons of water	Pounds	.1
.454	Pounds of water	Litres	.2202
70.3	lb/sq. inch	gms/sq. cm.	.0142
2.3	-do-	Head of water ft.	.434
0.7	-do-	,, M.	1.4285
.068	-do-	atmospheres	14.7
1.575	Tons/sq. inch	Kgm./mm^2	.635
4.883	Lbs/sq. ft.	Kgm./m^2	.205
.593	Lbs./Cubic yd.	Kgm./m^3	1.686
16.02	Lbs./Cubic ft.	Kgm/m^3	.0624
.0998	Lbs./gal.	Kgm./Litre	10.02
.138	Foot lbs.	Kgm. meters	7.23
.33	Foot Tons	Tonnes meters	3
1014	H. P.	Force-de-cheval	.9861
746	,,	Watts	.00134
33000	,,	Ft. lbs/min	—
76	,,	Kg. m/sec.	.01316
44	Watts	Ft. lbs./min	.0227
0.1	,,	Kg m/sec.	10
0.252	Heat units	Calories	3.97
14.7	Atmospheres	Lb./Sq. inch	.068
0.70	German candles	English Candles	1.1111
9.55	Carcels	Candles	.1047
.737	Joules	Ft. lbs.	1.357
88	Miles/hour	Ft./min	.01134
	To obtain	From	multiply by above.

Multiply by	To Convert	To	
197	meters/sec	Ft/min	.00508
1.8	C.H.O.	B.Th.U.	.5555
0.0208	Centipoise	Lbs/m^2 sec	48
1.488	lbs/ft	kgm litre	0.672
0.496	lbs/yd	-do-	2.016
3333.33	tons/ft	-do-	0.0003
1111.11	tons/yd	-do-	0.0009
0.2818	lb/mile	kgm/kilometer	3.548
10.936	tons/sft	tonnes/meter^2	0.0914
1.215	tons/syd	-do-	0.823
1.329	tons/cu. yd.	tonnes/m^3	0.752
0.01426	grains/gallon	gm/litre	70.12
48.905	gallons/sft	litres/m^2	0.0204
25.8	inch/tons	kgm/meters	0.0387
0.477	lbs/H.P.	kgm per cheval	2.235
0.0916	sft/H.P.	m/^{2} cheval	10.913
0.0279	cft/H.P.	m^3/cheval	35.806
2.713	Heat units/H.P.	calories/m^2	0.369
	To obtain	From	Multiply by above

METRIC EQUIVALENTS OF FEET & INCHES

(figures indicate metres)

Feet → Inches ↓	0	1	2	3	4	5	6	7	8	9	10	11	12
0	·0	·305	·610	·914	1·219	1·524	1·829	2·133	2·438	2·743	3·048	3·352	3·657
1	·0254	·330	·635	·940	1·244	1·549	1·854	2·158	2·463	2·768	3·073	3·378	3·682
2	·0508	·356	·660	·965	1·269	1·575	1·880	2·184	2·489	2·794	3·099	3·403	3·708
3	·0762	·381	·686	·991	1·295	1·600	1·905	2·209	2·514	2·819	3·124	3·429	3·733
4	·1016	·406	·711	1·016	1·320	1·626	1·931	2·235	2·540	2·844	3·150	3·454	3·759
5	·1270	·432	·737	1·041	1·346	1·651	1·956	2·260	2·565	2·870	3·175	3·479	3·784
6	·1524	·457	·762	1·066	1·371	1·676	1·981	2·285	2·590	2·895	3·200	3·505	3·810
7	·1778	·483	·787	1·092	1·397	1·702	2·007	2·311	2·616	2·921	3·226	3·530	3·835
8	·2032	·508	·813	1·117	1·422	1·727	2·032	2·336	2·641	2·946	3·251	3·555	3·860
9	·2286	·533	·838	1·142	1·1448	1·753	2·057	2·362	2·667	2·972	3·276	3·581	3·886
10	·2540	·559	·864	1·168	1·473	1·778	2·083	2·387	2·692	2·997	3·302	3·606	3·911
11	·2794	·584	·889	1·193	1·498	1·803	2·108	2·412	2·717	3·022	3·327	3·632	3·936

ENGLISH EQUIVALENTS OF CMS & MILLIMETERS

		0	1	2	3	4	5	6	7	8	9	10 cms.
m/m	0	·0	·3937	·7874	1·1811	1·5748	1·9685	2·3622	2·7559	3·1495	3·5433	3·9370 inches
	1	·0394	·4331	·8268	1·2205	1·6142	2·0079	2·4016	2·7953	3·1890	3·5827	
	2	·0787	·4724	·8661	1·2598	1·6535	2·0473	2·4410	2·8347	3·2284	3·6221	
	3	·1181	·5118	·9055	1·2992	1·6929	2·0866	2·4803	2·8740	3·2677	3·6614	
	4	·1575	·5512	·9449	1·3386	1·7323	2·1260	2·5197	2·9134	3·3071	3·7008	
	5	·1968	·5906	·9843	1·3780	1·7717	2·1654	2·5591	2·9528	3·3465	3·7402	
	6	·2362	·6299	1·0236	1·4173	1·8110	2·2047	2·5984	2·9922	3·3859	3·7796	
	7	·2756	·6693	1·0630	1·4567	1·8504	2·2441	2·6378	3·0315	3·4252	3·8189	
	8	·3150	·7087	1·1024	1·4961	1·8898	2·2835	2·6772	3·0709	3·4646	3·8583	
	9	·3543	·7480	1·1417	1·5354	1·9291	2·3228	2·7166	3·1103	3·5040	3·8977	

METRIC EQUIVALENTS:
(millimetres from inches and sixteenths)

Inch	0	1/16	1/8	3/16	1/4	5/16	3/8	7/16
0		1·58	3·17	4·76	6·35	7·93	9·52	11·11
1	25·400	26·98	28·47	30·16	31·74	33·33	34·92	36·51
2	50·799	52·38	53·97	55·56	57·14	58·73	60·32	61·91
3	76·199	77·78	79·37	80·96	82·54	84·13	85·72	87·31
4	101·60	103·19	104·77	106·36	107·95	109·54	111·12	112·71
5	127·00	128·59	130·17	131·76	133·35	134·94	136·52	138·11
6	152·40	153·98	155·57	157·16	158·75	160·33	161·92	163·51
7	177·80	179·38	190·97	182·56	184·15	185·73	187·32	188·91
8	203·20	204·78	206·37	207·96	209·55	211·13	122·72	214·31
9	228·60	230·18	231·77	233·36	234·94	236·53	238·12	239·71
10	254·00	255·58	257·17	258·76	260·35	261·93	263·52	265·11
11	279·39	280·98	282·57	284·16	285·74	287·33	288·92	290·51
12	304·79	306·38	307·97	309·56	311·14	312·73	314·32	315·91
13	330·19	331·78	333·37	334·96	336·54	338·13	439·72	341·31
14	355·59	357·18	358·77	360·36	361·94	363·53	365·12	366·71
15	380·99	382·58	384·17	385·76	387·34	388·93	390·52	392·11
16	406·39	407·98	409·57	411·16	412·74	414·33	415·92	417·50
17	431·79	433·38	434·97	436·56	438·14	439·73	441·32	442·90
18	457·19	458·78	460·37	461·96	463·54	465·13	460·72	468·30

METRIC EQUIVALENTS:
(millimeters from inches and sixteenths)

Inch	1/2	9/16	5/8	11/16	3/4	13/16	7/8	15/16
0	12·70	14·28	15·87	17·46	19·05	20·63	22·22	23·81
1	38·10	39·68	41·27	42·86	44·44	46·03	47·62	49·21
2	63·49	65·08	66·67	68·26	69·84	71·43	73·02	74·61
3	88·89	90·48	92·07	93·66	95·24	96·83	98·42	100·01
4	114·30	15·89	117·47	119·06	120·65	122·24	123·82	125·41
5	139·70	141·28	142·87	144·46	146·05	147·63	149·22	150·81
6	165·10	166·68	168·27	169·86	171·45	173·03	174·62	176·21
7	190·50	192·08	193·67	195·26	196·85	198·43	200·02	201·61
8	215·90	217·48	219·07	220·66	222·25	223·83	225·42	227·01
9	241·30	242·88	244·47	246·06	247·65	249·23	250·82	252·41
10	266·70	268·28	269·87	271·46	273·05	274·63	276·22	277·81
11	292·10	293·68	295·27	296·86	298·44	300·03	301·62	303·21
12	317·50	319·08	320·67	322·26	323·84	325·43	327·02	328·61
13	342·90	344·48	346·07	347·66	349·24	350·83	352·42	54·01
14	368·30	369·88	371·47	373·06	374·64	376·23	377·82	379·41
15	393·69	395·28	396·87	398·46	400·04	401·63	403·22	404·81
16	419·09	420·68	422·27	423·85	425·44	427·03	428·62	430·20
17	444·49	446·08	447·67	449·25	450·84	452·43	454·02	455·60
18	469·89	471·48	473·07	474·65	476·24	477·83	479·42	481·00

TABLE OF ENGLISH WEIGHTS EXPRESSED IN INDIAN WEIGHTS

English		Indian	English	Indian	English	Indian	English	Indian
Lbs.	2	Mds. Srs 1	16	21 31	34	925 22	90	2450 0
	4	2	18	24 20	36	980 0	92	2504 18
	6	3	Tons. 1	27 9	38	1034 18	94	2558 36
	8	4	2	54 18	40	1088 36	96	2613 13
	10	5	3	81 27	42	1143 13	98	2667 31
	12	6	4	108 36	44	1197 31	100	2722 9
	14	7	5	136 4	46	1252 9	200	5444 18
	16	8	6	163 13	48	1306 27	400	10888 36
	18	9	7	190 22	50	1361 4	500	13611 4
	20	10	8	217 31	52	1415 22	1000	27222 9
	22	11	9	245 0	54	1470 0		
	24	12	10	272 9	56	1524 18		
	26	13	11	299 18	58	1578 36		
Qrts.	1	14	12	326 27	60	1633 18		
	2	27	13	353 36	62	1687 31		
	3	1 1	14	381 4	64	1742 9		
Cwts.	1	1 14	15	408 13	66	1796 27		
	2	2 29	16	435 22	68	1851 4		
	3	4 3	17	462 31	70	1905 22		
	4	5 18	18	490 0	72	1960 0		
	5	6 32	19	517 9	74	2014 18		
	6	8 7	20	544 18	76	2068 36		
	7	9 21	22	598 36	78	2123 13		
	8	10 36	24	653 13	80	2177 31		
	9	12 10	26	707 31	82	2232 9		
	10	13 24	28	762 9	84	2286 27		
	12	16 13	30	816 27	86	2341 4		
	14	19 2	32	871 4	88	2395 22		

100 Mds = 3·673 Tons.

1 Ton = 27·22 Mds.

1 Md. = 82·29 Lbs.

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CHARTS

TABLES